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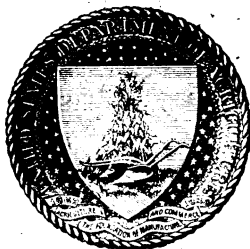
RECENT PRACTICE IN THE ERECTION OF LIGHTNING CONDUCTORS.

Prepared under the direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

BY

ALFRED J. HENRY,

PROFESSOR OF METEOROLOGY.



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1906.



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TO VIND
APPROVAL

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., February 2, 1906.

HON. JAMES WILSON,
Secretary of Agriculture.

SIR: I have the honor to transmit herewith a report entitled Recent Practice in the Erection of Lightning Conductors, by Alfred J. Henry, Professor of Meteorology, and to recommend its publication as a bulletin of the Weather Bureau.

Very respectfully,

WILLIS L. MOORE,
Chief U. S. Weather Bureau.

Approved.

JAMES WILSON, *Secretary.*

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RECENT PRACTICE IN THE ERECTION OF LIGHTNING CONDUCTORS.

By ALFRED J. HENRY, Professor of Meteorology.

It can not be said that there is any uniformity of practice in the erection of lightning conductors in the United States. In large cities one occasionally sees a residence on which they have been installed, more often a church, but very rarely a public building. The Federal Government does not install lightning conductors on any of the buildings it erects. In the case of powder magazines, however, the Ordnance Department of the Army provides a very complete system of protection from lightning. So too in the case of overhead electric power circuits that enter Federal buildings care is taken to protect the building from flashes that may come over the line. That the Government engineers are not without appreciation of the value of lightning conductors is evinced by the very complete system of protection installed upon the Washington Monument in 1885. In the application of lightning conductors to the monument the engineers in charge were guided by sound principles, and as might justly be expected, established a system of protection that has successfully performed its functions for more than 20 years. A detailed description is here reproduced since the original document is now inaccessible to the general public. (Senate Ex. Doc. No. 6, 49th Cong. 1st Session.)

LIGHTNING CONDUCTORS ON THE WASHINGTON MONUMENT.

The lightning conductors, as established for the monument, were commenced in January, 1880, and were finished in January, 1885. These conductors consist of 4 hollow wrought-iron Phoenix columns standing in the well of the shaft, and which support the elevator machinery and guide the car. These columns are 6 inches in exterior diameter, five-eighths of an inch in thickness, and are made up of sections 20 feet in length fastened together with long inside couplings, which fit tightly into the columns, and are fastened to them by 16 screw bolts. The bottoms of these 4 columns rest upon and are bolted to cast-iron shoes, which in turn stand upon the floor of the large drum pit beneath the floor of the monument. The shoes are connected to three-quarter inch soft copper rods led to the bottom of a well in the center of the foundation. This well is 32 feet 10 inches in depth below the bottom of the drum pit, and 15 feet 8 inches below the bottom of the masonry foundation, and the water stands in it permanently 2 feet 8 inches above its bottom. After the copper rods were inserted the well was filled with clean sharp sand for a depth of 15 feet 8 inches, or up to the level of the bottom of the old rubble-stone foundation of the monument. These 4 columns so arranged at their bases, and always projecting above the top of the shaft, were continually lengthened as the building of the shaft progressed, and for the 5 summers during which the masonry was in progress acted as the lightning conductors of the

edifice. No disruptive discharge of electricity was experienced during those 5 years.

When the walls were completed, in December of 1884, and the upper extremities of the columns were covered in by the marble pyramidion, 4 copper rods, three-quarters of an inch in diameter, were run, one from each column, to the top stone, and there united in a $1\frac{1}{2}$ inch copper rod, which passing vertically through the stone, was screwed into a solid metal terminal of aluminum. This metal was selected for the terminal because of its whiteness, and the probability that its polished surfaces would not tarnish upon exposure to the air. It was a square pyramid in shape, similar to the pyramidion of the obelisk, and, fitting upon the top stone, completed the apex. This terminal weighed 100 ounces, and was 8.9+ inches in height and 5.6+ inches in width at the base. The angle at the vertex between 2 opposite sides was about $34^{\circ} 48'$.

The conductors, as above described, when tested gave an electrical resistance of one-tenth of an ohm from the tip of the terminal to the copper rods at the base, and two and two-tenths ohms for the ground connections, making a total resistance of two and three-tenths ohms for the conductor. The system was entirely completed and connected on January 20, 1885.

On the 5th of April, 1885, during the passage of a heavy thunder cloud over the monument, at least 5 immense sparks or bolts of electrical light were seen within a period of 20 minutes to flash between the terminal and the cloud, without audible sound to the observers. A careful examination of the conductors and shaft after these phenomena failed to reveal any effects from these discharges.

On the 8th of June, however, during a thunderstorm, a disruptive discharge was seen to pass between the summit of the pyramidion and the cloud. Upon examining the structure a crack was discovered in the stone on the north face of the pyramidion just under the top stone, extending through the block in a line nearly parallel to the northeast corner, and about eight and one-half inches from it. The fragment was pressed outwards about three-quarters of an inch at its bottom, chipping a small piece off the lower corner of the top stone into which it was locked, and was easily forced back to place and bolted to the solid stone from which it had been torn.

Under the circumstances of this damage, and to devise if possible some plan by which the obelisk could be more effectually protected from lightning, Professors H. A. Rowland, of the Johns Hopkins University, Simon Newcomb, of the United States Navy, and T. C. Mendenhall, of the United States Signal Service, were invited to inspect the conductors and recommend any modifications in them, which in their judgment would be proper for the end required. This they kindly consented to do, and after a careful examination recommended, in substance, that the interior conductors should be connected with a system of rods and a greater number of points to be located upon the exterior of the pyramidion. The additions, as devised by them, consist of 4 one-half inch copper rods, fastened by a band to the aluminum terminal and led down the corners to the base of the pyramidion; thence passing through the masonry they extend inward and are joined to the iron columns above described. As these exterior rods are each over 60 feet long, they are also connected at two intermediate points of their lengths with the iron columns by means of copper rods one-half and three-quarters of an inch, respectively, furnishing sixteen rods in all connecting the exterior system of conductors with the interior conducting columns. Where the exterior rods upon the corners cross the eleven highest horizontal joints of the masonry of the pyramidion, they are connected to each other all around by other copper rods sunk into those joints. All of these exterior rods, couplings, and fittings are cold plated, and are studded at every 5 feet of their lengths with copper points 3 inches in length, gold plated and tipped with platinum. There are 200 of these rods in all. * * *

LIGHTNING CONDUCTORS IN URBAN DISTRICTS.

In urban districts the application of lightning conductors to farm and residence buildings is much more common than in the larger towns and cities. Whether or not lightning conductors shall be installed on buildings is generally determined by the individual judgment of the owner. So far as known, the architects' plans, when such are used, do not provide for lightning conductors.

APPARENT DECREASE IN USE OF LIGHTNING CONDUCTORS.

It seems probable that there has been a decided falling off in the use of lightning conductors within the last 30 years. According to the United States Census statistics, there were, in 1860, twenty establishments manufacturing lightning rods, which turned out a product valued at \$182,750. In 1870 the number of establishments had risen to 25 and the value of the products to \$1,374,631. In the next decade the number of establishments fell to 20 and the value of the product to \$801,192, and finally in 1890 the number of establishments rose to 22, but the value of the product diminished to \$483,296. At the census of 1900 the classification in vogue from 1860 to 1890 was abandoned and lightning rods were tabulated in the general classification "Foundry and Machine Shop Products." There are no means of determining absolutely whether the large decrease in the value of the manufactured product from 1870 to 1890 marks a decline in the use of lightning conductors; certain it is, however, that the "Lightning Rod Man" is not so much in evidence as he was in the early seventies.

The possibilities and the limitations of a properly installed lightning rod are fully set forth on the pages which follow. In general the conclusions therein reached are in close accord with those of the Weather Bureau officials who have given attention to the subject. In large cities the use of lightning rods is not imperative owing to the prevalence of modern steel structures and in general buildings with metal roofs. For buildings that stand isolated in the open country the prudent course would be to install thereon a system of protection from lightning. The extent to which the building should be protected and naturally the expense of installation should bear some definite relation to the value of the building. If the building is insured against loss by fire or lightning, it would not seem advisable to go to the additional expense of erecting lightning rods. In any event the final decision must be reached by the owner of the building. In arriving at his decision he should be guided by the fact that, while absolute security from damage by lightning is attainable only with great difficulty and considerable expense, a reasonable degree of protection can be secured by very simple means, provided the system of protection be devised and erected by a thoroughly competent person.

REPORT OF LIGHTNING RESEARCH COMMITTEE. (GREAT BRITAIN.)

There recently appeared in the Journal of the Royal Institute of British Architects, Third Series, Volume XII, No. 13, a report made by the Lightning Research Committee, a committee that was formed for the purpose of obtaining trustworthy information on disasters suffered by buildings from lightning, of investigating causes of failure of lightning conductors to protect, and finally of suggesting, if possible, improved means of protection. A short preface to the report was written by Sir Oliver Lodge, F. R. S. Both the preface and the report of the committee contain so much information of value to American architects and builders that a very full abstract is here given. Acknowledgment is made of our indebtedness to the committee which formulated the report, as well as to the Journal of the Royal Institute of British Architects, which published it.

REPORT OF THE LIGHTNING RESEARCH COMMITTEE. (GREAT BRITAIN.)

PREFACE.

By Sir OLIVER LODGE, F. R. S.

Since the report, many years ago, of the Lightning Rod Conference knowledge of the subject has considerably increased and the effect of self-induction, which then was completely ignored, has been taken into account and understood. The main differences between what is recommended to-day and what was considered sufficient then depend on the recognition of the influence of self-induction or electrical inertia. Then electricity was treated as if it had no inertia, and as if all that was necessary was to get it from the clouds to the earth as quickly and easily as possible by the shortest path, which may be called the drain-pipe theory. It was supposed that it would always take the easiest path, and that the easiest path would protect all others. Attention was directed to the quantity of electricity which had to be conveyed down, and to nothing else.

Now, however, it is perceived that it is not so much quantity of electricity that has to be attended to as electrical energy; that this electrical energy is stored between clouds and earth in dangerous amount, and that our object should be to dissipate it not as quickly but as quietly as possible. A sudden dissipation of energy is always violent. No one in his senses wishes to stop a fly wheel or a railway train suddenly; sudden or hasty dissipation is not what is wanted. Gun cotton possesses a store of potential energy locked up in it to a dangerous extent; if it be dissipated suddenly, as by percussion, a violent explosion results; but if it be dissipated gradually, as by a flame, the energy is got rid of without much damage, beyond the liability to fire. An armor plate may be able to stop a cannon ball quickly, but a heap of sand or loose earth does it more safely, because more gradually.

So it is exactly with the store of energy beneath an electrified cloud or between one cloud and another. A lightning conductor of perfect conductivity, if struck, would deal with the energy in far too rapid and sudden a manner, and the result would be equivalent to an explosion. A conductor of moderately high resistance, such as an iron wire, would get rid of it in a slower and therefore much safer and quieter manner, though with too thin a wire there may be risk of fire.

The rush in any case, however, is likely to be rather violent, and, like an *avalanche*, it will not take the easiest path provided for it, as if it were a trickling stream, but will crash through obstacles and make its own path, some portions

of it taking paths which would be quite unexpected. Hence, no one path can be said to protect others, and the only way to protect a building with absolute completeness is to inclose it wholly in metal. An invisible cage or framework of iron wires, however, descending vertically down its salient features, with the utilization of any metal in its construction, suffices for all practical purposes, unless the building is a powder magazine.

The effect of *points*, and of rain also, in gradually dissipating a charge, and thereby contributing to safety, has long been understood; but the feature which has not been known is that there are cases where points are wholly inoperative, viz, when the energy is stored between cloud and cloud, instead of between cloud and earth, and when the initial discharge takes place from one cloud to another; then the lower cloud is liable suddenly to overflow to earth through a region in which there was no previous preparation, and where any number of points, or a rain shower, or any other form of gentle leak, would have been quite inoperative. Then can a violent discharge occur to even the sharpest point; and a hot column of air, such as rises up a chimney, is even preferred to a conductor. These are the flashes against which points and rain are no protection, and these are probably those which do the most damage to protected buildings. But it must be understood that when a flash does occur through a building, it matters little which kind of flash it is—both can be equally sudden and violent—but if the building is well provided with points, the first or prepared kind is not likely to occur, save in exceptional cases, the dangerous liability is then the sudden or overflow variety of flash.

These, then, are the two points of novelty:

1. The possible occurrence of a totally unprepared-for and sudden flash in previously unstrained air, by reason of overflow from a discharge initiated elsewhere, what is called the *B* spark, occurring as the secondary result of an *A* spark.

2. The effect of electrical inertia or momentum, so that the discharge is not a simple leak or flow in one direction, but a violent oscillation and splash or impulsive rush, much more like an explosion, and occurring in all directions at once, without much regard to the path which had been provided for it; no more regard, in fact, than is required to enable the greater part of it to take the good conductors, and to prevent any part of it from being able to enter a perfectly inclosed metallic building.

Even a small lateral fraction of a flash is able, however, to ignite gas if there is a leak, or even to *make* a leak at a "compo"-pipe where it is crossed by a bell wire, and then ignite it; hence, after a building has been struck, careful watch should be kept for some time against the danger of fire.

The amount of protection to be allotted to any building is no doubt analogous to the question of insurance generally; that is to say, the amount of premium it is desired to pay may be compared with the capital at stake and the risk run; and this is doubtless a matter for individuals and public bodies to consider for themselves. What the committee can do is to make a study of cases of damage occurring to buildings which on the old lines were supposed to be protected, to tabulate them as below, and to ask for carefully recorded observations; they can also draw up such hints and suggestions as may be of use to architects whose clients desire their buildings to be protected in a more thorough, but not necessarily a more expensive manner.

These objects, and these attempts at being useful, explain the existence of the present report.

OBSERVATIONS AND SUGGESTIONS.

It has been pointed out by Sir Oliver Lodge that lightning discharges are of two distinct characters, which he has named the *A* flash and the *B* flash, respectively.

The *A* flash is of the simple type which arises when an electrically charged cloud approaches the surface of the earth without an intermediate cloud intervening, and under these conditions the ordinary type of lightning conductor acts in two ways: first, by silent discharge; and secondly, by absorbing the energy of a disruptive discharge. In the second type, *B*, where another cloud intervenes between the cloud carrying the primary charge and the earth, the two clouds practically form a condenser; and when a discharge from the first takes place into the second the free charge on the earth side of the lower cloud is suddenly relieved, and the disruptive discharge from the latter to the earth takes such an erratic course *that no series of lightning conductors of the hitherto recognized type suffice to protect the building.*

On the 28th of May, 1904, an interesting demonstration of the action of *A* and *B* flashes, respectively, was given by Sir Oliver Lodge before members of the committee and others interested in these researches. A thin sheet of metal mounted on nonconducting standards represented the cloud, which was charged at will from a Leyden jar. The "cloud" was so arranged that the model lightning conductors could have their points brought nearer to or farther from its under surface by shifting their positions on the table. Conductors of copper, iron, and wet string were experimented with. The disruptive discharge to the copper proved to be by far the loudest and most intense of the three. The iron took the flash with less noise, the wet string, with hardly any; yet when the discharge passed through it the other and apparently better conductors were not affected. The experiments tended to demonstrate that iron is in many situations a very useful material for lightning rods, as the effective energy of a flash of lightning is rapidly dissipated in iron. This metal, however, unfortunately oxidizes rapidly in towns and smoky districts, and the use of copper as a material for a lightning rod is still recommended for main conductors in relatively inaccessible positions, although iron is electrically preferable.

A consideration of the descriptions of recent foreign practice given in Appendix B, and of the cases which appear in the summary of damage, Appendix A, (not here reprinted) justifies the following general observations:

It is probable that with few exceptions buildings in this country are not in reality efficiently protected against the effects of a *B* flash, although in many cases the lightning conductors may be said to have at least partially fulfilled their purpose by carrying off the more violent portion of a discharge, and that without them greater damage would have occurred in many of the cases reported.

Some of these observations throw a very interesting light on the effects due to the oscillatory character of lightning discharges. For instance, a discharge takes place over a lightning rod which may be in contact with, or approach closely to, the metallic portions of a roof. Powerful electrical oscillations are set up in the latter conductors, and dangerously high electrical pressure may be generated on the distant ends of these conductors. If at these points they were connected to earth the pressure would be relieved, and the discharge harmlessly dissipated. Without this safe path the discharge may break away into the down pipes, or may pierce the roof to reach internal conductors. Cases which appear to indicate successive or simultaneous flashes may be due to a single flash setting up these oscillations.

In some cases the damage done to a building by an *A* flash is not necessarily due to the primary discharge. A lateral discharge occasionally occurs which frequently causes minor, though in some cases serious, damage owing to falling materials.

Many of the reports of damage to unprotected buildings show that the lightning *discharge followed the path of wire ropes, metallic pipes, and other conductors, and that the damage to the structure occurred at the breaks in continuity at the upper and lower terminals, respectively.*

It may be considered that a lightning conductor of the ordinary type, if properly constructed, affords an undefined area of protection against *A* flashes, but it can not be said to have any protective area against *B* flashes.

Absolute protection of the whole of a building could only be assured by inclosing the structure in a system of wirework—a contrivance, in fact, of the nature of a bird cage. This should be well connected at various points to earth, as nearly all buildings have gas and water pipes and other metallic conductors in their interiors which are likewise earthed. For structures intended for the manufacture or storage of gunpowder and other explosives the adoption of this bird cage protection would be justified on the score alone of public safety. Architectural considerations prevent the adoption of such a method in its entirety for ordinary buildings. There is no doubt, however, that practically perfect protection may be assured by a judicious modification of the existing practice of erecting single lightning rods, especially in the case of extensive and lofty buildings that project well above surrounding structures or that stand isolated in the open country.

It is obvious that the extent to which the building should be protected and the expense to be incurred in this protection must bear some definite relation to the importance or cost of the building itself. In cases where protection is considered desirable, but heavy expense is not justified, two or more lightning rods might be erected in the ordinary manner, these being connected by a horizontal conductor, and the metal portions of the roof and the rain water down pipes should be metallically connected and well earthed.

Tall chimney shafts are not efficiently protected against a *B* flash by an ordinary single lightning rod, as a hot column of smoke issuing from a chimney conducts as well or even better than a rod. A circular band should surround the top of the shaft; four or more conductors should be raised above the latter in the form of a coronal, or the continental practice of joining the elevation rods together, so as to form an arch over the chimney, may be employed with advantage. One or, preferably, two lightning rods should extend from this circular band to the earth in the manner described below.

As most buildings contain systems of gas and water pipes, a good earth for the lightning conductors is highly desirable. In the case of a stove inside a building with a metallic stovepipe carried outside the stove should be earthed and a wire be led from the pipe to earth outside, or to the nearest conductor.

The various cases noted by the committee show that while even single conductors tend to diminish the damage done to buildings by lightning no reliance can be placed on an area of protection. Judging by the latest foreign practice, continental experience appears to be confirmatory of this view (see Holland, Hungary, and Germany, Appendix B). In churches and other buildings with spires and towers the lower projections should also be protected, even if forming part of the salient features of the building.

No cases of damage to modern steel frame structures have come under the notice of the committee. The ordinary method of construction, however, in this country does not provide full protection. In many cases the steel columns stand on stone foundations and the metal is not carried deep enough for effective earthing. The metal columns ought to be earthed at the time of construction.

In the opinion of the committee, the methods advocated in the Report of the Lightning Rod Conference still hold good, provided arrangements are made to keep the earth permanently moist. The committee therefore deems it convenient to print here the rules issued by the Lightning Rod Conference in 1882, supplementing them with observations and suggestions of their own based on the results of their recent *researches*.

RULES FOR THE ERECTION OF LIGHTNING CONDUCTORS, AS ISSUED BY THE LIGHTNING ROD CONFERENCE IN 1882, WITH OBSERVATIONS THEREON BY THE LIGHTNING RESEARCH COMMITTEE, 1905.

[NOTE. — Paragraphs beginning with odd numbers refer to Lightning Rod Rules, 1882; those with even numbers to Lightning Research Committee's observations, 1905.]

1. **POINTS.**—The point of the upper terminal should not be sharp, not sharper than a cone of which the height is equal to the radius of its base. But a foot lower down a copper ring should be screwed and soldered on to the upper terminal, in which ring should be fixed three or four sharp copper points, each about 6 inches long. It is desirable that these points be so platinized, gilded, or nickel plated as to resist oxidation.

2. It is not necessary to incur the expense of platinizing, gilding, or electroplating. It is desirable to have three or more points beside the upper terminal, which can also be pointed; these points must not be attached by screwing alone, and the rod should be solid and not tubular.

3. **UPPER TERMINALS.**—The number of conductors or points to be specified will depend upon the size of the building, the material of which it is constructed, and the comparative height of the several parts. No general rule can be given for this, but the architect must be guided by the directions given. He must, however, bear in mind that even ordinary chimney stacks, when exposed, should be protected by short terminals connected to the nearest rod, inasmuch as accidents often occur owing to the good conducting power of the heated air and soot in the chimney.

4. This is dealt with below in suggestion 3 (page 16).

5. **INSULATORS.**—The rod is not to be kept from the building by glass or other insulators, but attached to it by metal fastenings.

6. This regulation stands.

7. **FIXING.**—Rods should preferentially be taken down the side of the building which is most exposed to rain. They should be held firmly, but the holdfast should not be driven in so tightly as to pinch the rod or prevent the contraction and expansion produced by changes of temperature.

8. In most cases it would be advantageous to support the rods by holdfasts (which should be of the same metal as the conductor) in such a manner as to avoid all sharp angles. The vertical rods should be carried a certain distance away from the wall to prevent dirt accumulating and also to do away with the necessity of their being run round projecting masonry or brickwork.

9. **FACTORY CHIMNEYS.**—These should have a copper band around the top, and stout, sharp copper points, each about one foot long, at intervals of two or three feet throughout the circumference, and the rod should be connected with all bands and metallic masses in or near the chimney. Oxidation of the points must be carefully guarded against.

10. As an alternative, the rods above the band might with advantage be curved into an arch provided with three or four points. It is preferable that there should be two lightning rods from the band carried down to earth in the manner previously described. Oxidation of the points does not matter.

11. **ORNAMENTAL IRONWORK.**—All vanes, finials, ridge ironwork, etc., should be connected with the conductor, and it is not absolutely necessary to use any other point than that afforded by such ornamental ironwork, provided the connection be perfect and the mass of ironwork considerable. As, however, there is a risk of derangement through repairs, it is safer to have an independent upper terminal.

12. Such ironwork should be connected as indicated below in suggestion 3. In the case of a long line of metal ridging a single main vertical rod is not sufficient, but each end of the ridging should be directly connected to earth by a rod. Where *the ridge is nonmetallic a horizontal conductor (which need not be of large sectional area) should be run at a short distance above the ridge and be similarly connected to earth.*

13. **MATERIAL FOR ROD.**—Copper, weighing not less than 6 ounces per foot run, and the conductivity of which is not less than 90 per cent of that of pure copper, either in the form of tape or rope of stout wires—no individual wire being less than No. 12 B. W. G. Iron may be used, but should not weigh less than $2\frac{1}{4}$ pound per foot run.

14. The dimensions given still hold good for main conductors. Subsidiary conductors for connecting metal ridging, etc., to earth may with advantage be of iron and of a smaller gage, such as No. 4 S. W. G. galvanized iron. The conductivity of the copper used is absolutely unimportant, except that high conductivity increases the surges and side flashes, and, therefore, is positively objectionable. It is for that reason that iron is so much better.

15. **JOINTS.**—Although electricity of high tension will jump across bad joints, they diminish the efficacy of the conductor; therefore every joint, besides being well cleaned, screwed, scarfed, or riveted, should be thoroughly soldered.

16. Joints should be held together mechanically as well as connected electrically, and should be protected from the action of the air, especially in cities.

17. **PROTECTION.**—Copper rods to the height of 10 feet above the ground should be protected from injury and theft by being inclosed in an iron pipe reaching some distance into the ground.

18. This regulation stands.

19. **PAINTING.**—Iron rods, whether galvanized or not, should be painted; copper ones may be painted or not according to architectural requirements.

20. This regulation stands.

21. **CURVATURE.**—The rod should not be bent abruptly round sharp corners. In no case should the length of the rod between two points be more than half as long again as the straight line joining them. Where a string course or other projecting stonework will admit of it, the rod may be carried straight through, instead of round the projection. In such a case the hole should be large enough to allow the conductor to pass freely, and allow for expansion, etc.

22. The straighter the run the better. Although in some cases it may be necessary to take the rod through the projection, it is better to run outside, keeping it away from the structure by means of holdfasts, as described above.

23. **EXTENSIVE MASSES OF METAL.**—As far as practicable it is desired that the conductor be connected to extensive masses of metal, such as hot-water pipes, etc., both internal and external; but it should be kept away from all soft metal pipes, and from internal gas pipes of every kind. Church bells inside well-protected spires need not be connected.

24. It is advisable to connect church bells and turret clocks with the conductors.

25. **EARTH CONNECTIONS.**—It is essential that the lower extremity of the conductor be buried in permanently damp soil; hence proximity to rain-water pipes, and to drains, is desirable. It is a very good plan to make the conductor bifurcate close below the surface of the ground, and adopt two of the following methods for securing the escape of the lightning into the earth. A strip of copper tape may be led from the bottom of the rod to the nearest gas or water *main*—not merely to a lead pipe—and be soldered to it; or a tape may be soldered to a sheet of copper 3 feet by 3 feet and $\frac{1}{8}$ -inch thick, buried in permanently wet earth, and surrounded by cinders or coke; or many yards of the tape may be laid in a trench filled with coke, taking care that the surfaces of copper are, as in the previous cases, not less than 18 square feet. Where iron is used for the rod, a galvanized-iron plate of similar dimensions should be employed.

26. The use of cinders or coke appears to be questionable owing to the chemical or electrolytic effect on copper or iron. Charcoal or pulverized carbon (such as ends of arc-light rods) is better. A tubular earth consisting of a perforated steel spike driven tightly into moist ground and lengthened up to the surface, the conductor reaching to the bottom and being packed with granulated charcoal, gives as much effective area as a plate of larger surface, and can easily be kept moist by connecting it to the nearest rain-water pipe. The resistance of a tubular earth on this plan should be very low and practically constant.

27. **INSPECTION.**—Before giving his final certificate the architect should have the conductor satisfactorily examined and tested by a qualified person, as injury to it often occurs up to the latest period of the works from accidental causes, and often from carelessness of workmen.

28. Inspection may be considered under two heads:

A. The conductor itself.

B. The earth connection.

A. Joints in a series of conductors should be as few as possible. As a rule they should only be necessary where the vertical and horizontal conductors are connected, and the main conductors themselves should always be continuous and without artificial joints. Connections between the vertical and horizontal conductors should always be in places readily accessible for inspection. Visible continuity suffices for the remainder of the circuit. The electrical testing of the whole circuit is difficult, and needless.

B. The electrical testing of the earth can in simple cases be readily effected. In complex cases, where conductors are very numerous, tests can be effected by the provision of test clamps of a suitable design.

29. **COLLIERIES.**—Undoubted evidence exists of the explosion of fire-damp in collieries through sparks from atmospheric electricity being led into the mine by the wire ropes of the shaft and the iron rails of the galleries. Hence the head gear of all shafts should be protected by proper lightning conductors.

SUGGESTIONS OF THE COMMITTEE.

The investigations of the committee warrant them in putting forward the following practical suggestions:

1. Two main lightning rods, one on each side, should be provided, extending from the top of each tower, spire, or high chimney stack by the most direct course to earth.

2. Horizontal conductors should connect all the vertical rods (a) along the ridge, or any other suitable position on the roof; (b) at or near the ground.

3. The upper horizontal conductor should be fitted with aigrettes or points at intervals of 20 or 30 feet.

4. Short vertical rods should be erected along minor pinnacles and connected with the upper horizontal conductor.

5. All roof metals, such as finials, ridging, rain water, and ventilating pipes, metal cowls, lead flashing, gutters, etc., should be connected to the horizontal conductors.

6. All large masses of metal in the building should be connected to earth either directly or by means of the lower horizontal conductor.

7. Where roofs are partially or wholly metal lined they should be connected to earth by means of vertical rods at several points.

8. Gas pipes should be kept as far away as possible from the positions occupied by lightning conductors, and as an additional protection the service mains to the gas meter should be metallically connected with house services leading from the meter.

(Signed)

JOHN SLATER, *Chairman*,
E. ROBERT FESTING,
OLIVER LODGE,
J. GAVEY,
W. N. SHAW,
A. R. STENNING,
ARTHUR VERNON,
KILLINGWORTH HEDGES,
Honorary Secretary,
G. NORTHOVER, *Secretary*.

APPENDIX B.

LATEST PRACTICE ABROAD.

Holland.

The following is translated from the Dutch of the very complete and valuable report made by Dr. D. van Gulik at the request of the Dutch Academy of Science, which has just been published under the title of Further Inquiries in Regard to the Protection of Buildings from Lightning (Haarlem, 1905):

1. Lightning conductors serve to lessen the risk of fire and of serious damage for the buildings protected by them, and to reduce considerably the danger to life for those who inhabit the buildings. Whether the risk of a building being struck by lightning is also lessened by the installation of points or bundles of points is very doubtful. Where, therefore, economy is an object these may be first dispensed with.

2. In protecting buildings from lightning we must bear in mind that, contrary to what we notice in the case of constant electric currents—

(a) Lightning shows a great tendency to distribute itself over such conductors as may be present, and in so doing to pay little heed to the electrical resistance of the conductor.

(b) That it finds no great difficulty in making its way, often for a considerable distance, through the air or through any other good conducting medium.

(c) That it prefers to move, as far as possible, in a straight line, and that, therefore, sharp turns or spiral windings in conductors present hindrances which, in view of the properties mentioned in paragraphs a and b, readily lead to lateral discharges.

Absolute security is not attainable or attainable only with great difficulty, and in any case at considerable expense. On the other hand a quite satisfactory degree of protection can be secured by very simple means.

3. The greater the importance attached to the preservation of a building and its contents the more perfect can the system of conductors be made, and thus a higher coefficient of safety is obtained by increased expenditure.

4. The conductors at present used in Holland secure a fairly high degree of safety in the case of houses with tiled or slated roofs, as they reduce the risk of fire when struck to an average of between one-sixth or one-seventh. Statistics show, however, that the lightning frequently diverges from them and may even strike the buildings without touching the terminal rods. Moreover, the cost of installation is so great that many people are deterred thereby from having these useful appliances fitted. Certain general improvements and simplifications may, however, be pointed out, by means of which the conductors would, even at a lower cost, better answer the purpose for which they are intended.

5. The *improvements* are in the main as follows:

(a) All salient positions liable to be struck should be provided with terminals in the form of short rods or wires, and the roof should be girt round on all sides by wire conductors. This would take the place of the high terminal rods with their imaginary cone of safety.

(b) Several conductors running to the earth should be fitted.

(c) The system of conductors should be connected with any extensive metallic mass present in the building, if necessary at more points than one. In the case of gas and water pipes such connection is absolutely necessary.

6. The principal *simplifications* may be summed up thus:

(a) High terminal rods should be abolished, as it is difficult to fix them firmly enough.

(b) Copper, which is the material generally used for conductors and earth connections, should be replaced by iron. This, if well galvanized, will resist atmospheric influences for a very long time and can, moreover, be easily protected by a coat of paint.

(c) The thickness of the conductors should be reduced. In support of this we may adduce the evidence of the ordinary telegraph wire, which is seldom, if ever, found to be melted, except at the point where it is struck. Even in providing for extreme cases we should not lose sight of the fact that a wire will do its duty even though it succumbs to the force of the stroke.

(d) The metallic constructional portions of the building should be pressed into service as conductors. By this means either the conducting system is extended, with a consequent increase in the margin of safety, or the use of special conductors may be partly dispensed with. This last expedient proves a ready means, in the case of special classes of buildings, of providing quite efficient conductors at a trifling cost. It is not necessary that there should be metallic contact between the metal constructions provided that they overlap one another over an area of 10 square centimeters.

7. In making earth connections too much importance is often attached to reaching the ground water level, while on the other hand too little care is taken to secure a good connection between the conductor and the uppermost layer of soil. By paying attention to this a considerable saving may in some cases be made in the cost of earth contact. In isolated cases where connection with underground pipes, etc., is possible, no special earth connection is necessary.

8. When building houses it is desirable that the conductors should always be marked on the plans. This makes their installation easier and reduces the cost. Moreover, it enables architects to exclude from their plans constructions which would tend to increase the risk of fire in the event of the house being struck by lightning.

9. Special precautions are necessary in the case of thatched roofs. These consist mainly in keeping the conductors some distance away from the roof and in making the wire of such thickness that it shall not be destroyed at the point where it is struck by lightning. If this be done, a high degree of safety is attainable even in the case of thatched roofs.

Hungary.

Through the good offices of the Rector of the Royal Joseph Polytechnical University, Budapest, Dr. Moritz von Hoór kindly favored the committee with the following remarks concerning the precautions against lightning now coming into use in Hungary, showing the method of their installation and their efficacy as proved by experience:

Up to the year 1892, in Hungary as well as in other countries, lightning conductors with collecting points according to the Franklin system were the only ones in use. Here, as elsewhere, the view was universally accepted that absolute security for the efficiency of lightning conductors was afforded by the largest possible cross section of the lightning rod, by a slight change of the collecting apparatus, and by a good earth connection. It was held, therefore, that a conductor had been rightly set up when the collecting point and the earth had been connected by strong copper wires or cables, and care had been taken for a good earth contact.

Experience of such lightning conductors, however, as well as observations systematically taken in England and the English colonies, and in Germany, proved that lightning rods on this principle did not answer their purpose, and in particular that the directions as to the area of protection of the conductor and the *relation between height and base* of the protected zone were of no practical value and quite baseless.

It was repeatedly observed that there were lateral discharges from the conductor in the direction of the metal parts (badly connected apparently with the earth), that sparks leaped over curves in the conduction apparatus, and in general that buildings and other objects protected by the collecting points suffered damage from lightning, though to a far less extent, as shown by statistics, than objects altogether unprovided with lightning conductors.

Prof. Moritz von Hoór, following up the work of Hertz and Lodge, was the first in our country to treat this question theoretically and experimentally in a scientific manner on the basis of the new principles, and he was the first here to suggest the abandonment of the conductors with collecting points, and the introduction of contour conductors without collecting points similar to Faraday's parrot cage.

Leopold Stark, chief engineer of Messrs. Ganz & Co., has since made an exhaustive study of this question, and has worked out various practical plans for cage conductors, with a special view to their application to the protection of agricultural objects peculiarly exposed to risks from lightning (cf. *Villámhárítók különös tekintettel mezőgazdasági épületekre*, Irta: Stark Lipót gépészmérnök, Budapest, Fővárosi Nyomda, 1903).

For some years now, as a result of these works and of the agitation started by the above-mentioned scientists, cage lightning conductors of this kind have been largely in use with us, both on town buildings and on agricultural objects. They consist, as Sir Oliver Lodge, and, long before him, Faraday, suggested, of barbed wire, or strong iron wire, or sheet iron bands, which, following the contours of the roof and building or other objects conduct to separate earth connections or to connections joined underground by a circular conducting wire.

The cost of such conductors is with us hardly more than that of the conductors with gilt collecting points and copper conducting wires, and they have been found admirably efficacious as might have been deduced from theoretical reasoning, so that the military authorities both in Austria and Hungary have had all magazines of explosives protected in this manner.

Special care is taken, in setting up these cage conductors, to avoid the sharp curves arising from a sudden change in the direction of the earth conductors, so as to reduce as far as possible the self-induction of the earth connection.

Importance is also attached to good earths, but experience shows that if the cage arrangement is well carried out and the number of cage wires not too scanty, even without a very good earth connection, the conductor still works satisfactorily.

At present both the cage and the Franklin collecting point systems are in use with us; but of late years, especially for agricultural objects, the cage system is coming more and more in vogue, and probably in a short time all the new conductors will be of this kind.

Germany.

The following is extracted from the Regulations of the Electro-Technical Society of Berlin, issued in 1901:

1. The lightning receivers should consist of vertical points. The points of towers or gables, edges of the ridge of the roof, tops of chimney stacks, and other high parts of buildings should be converted into receivers or be provided with suitable receivers. The conductors should be in metallic connection with the receivers and the earth; they should go round the building, especially in the roof, and if possible on all sides, and then be led from the receivers to the ground by the most direct route, avoiding as much as possible all sharp curves. The earth connections should consist of metallic conductors connected to the lower conductors on the building, and should descend into the ground and extend as far as possible, preferably where the earth is damp.

2. The metallic parts of the building and masses of metal in and upon it, especially those in contact with the earth and offering large surfaces (such as pipes),

should be connected together as much as possible, and to the conductor also. Special receivers and conductors are rendered unnecessary if these metallic parts of the building comply with the requirements mentioned in paragraphs 1, 4, and 5. Both for perfecting the system and for decreasing cost, the question of utilizing the pipes as conductors should be considered when erecting new buildings, making use also as much as possible of all the metallic parts of the building for protective purposes.

3. The protection afforded by a conductor is the greater the more perfectly all the prominent portions of the building are protected by receivers, the larger the number of receivers and conductors, and the more extended the connections to earth. Generally speaking, damage by lightning is diminished if all the metallic parts of buildings of considerable extent are interconnected, especially if the highest parts are connected to earth, even if these connections are not made specially with a view to protection from lightning.

4. Interconnected conductors of iron should not have a section of less than 50 square millimeters, unconnected ones not less than 100 square millimeters. If of copper, half the section is sufficient; zinc must be one and a half, and lead three times the section for iron. Conductors must be securely fixed to resist strong winds.

5. The connections of and to the conductors must be made strong, be of good electrical contact, and with as large a surface as possible. Unwelded and unsoldered connections should have metallic surfaces of contact of not less than 10 square centimeters.

The lightning-conductor system should be repeatedly tested; and when alterations are made in the building, the necessity of alterations in the lightning-conductor system should be considered.

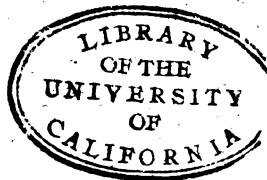
Baurat Findelsen, of Stuttgart, deduces from certain statistics as to strokes by lightning in Württemberg that there is some doubt as to the efficacy of intercepting rods in attracting and protecting against lightning, and that there is no point in measuring the resistance of lightning conductors, since the high pressure of lightning would overcome even high degrees of resistance. It would be sufficient, he thinks, if all the protecting sheet metal on the roof ridge and elsewhere were connected with the gutters and rain-water pipes—if the chimney, which is so often struck, were protected by a rope (3 to 4 mm.) of galvanized iron wire, projecting to a height of one-half to one meter above the chimney, and joined as a conductor with the protecting metal, and if the water pipes were used as earth connections, they also having a strong wire rope running along them, which, at the lower end should be untwisted and carried in fan shape about a meter down into the ground. Four such earth connections at the corners of the building to be protected would suffice. If yet further precautions are desired, galvanized sheet iron might be substituted for this. Lightning conductors of this type have proved their efficiency.

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U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.



MISSISSIPPI RIVER LEVEES AND THEIR EFFECT ON RIVER STAGES DURING FLOOD PERIODS.

Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

BY

SAMUEL C. EMERY,

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., June 7, 1910.

The Honorable,
The Secretary of Agriculture,
Washington, D. C.

SIR: I have the honor to transmit herewith a paper by Mr. Samuel C. Emery, Local Forecaster in charge of the local office of the Weather Bureau at Memphis, Tenn., on "Mississippi River Levees and their Effect on River Stages During Flood Periods."

I recommend the publication of this paper as a bulletin of the Weather Bureau.

Very respectfully, your obedient servant,

WILLIS L. MOORE,
Chief United States Weather Bureau.

Approved.

JAMES WILSON,
Secretary of Agriculture.

MISSISSIPPI RIVER LEVEES AND THEIR EFFECT ON RIVER STAGES DURING FLOOD PERIODS.

The Mississippi River, following its winding course from near Lake Itasca, in northern Minnesota, to the Gulf of Mexico, is about 2,446¹ miles in length. The head waters of its tributaries extend from New York on the east to northern Montana on the west, and its drainage area is 1,242,600 square miles, about two-fifths of the total area of the United States. The river is navigable throughout from St. Paul, Minn., to its mouth, a distance of 1,954 miles. The head of navigation is Cass Lake² about 2,380 miles from its mouth, and the total navigable length of the entire system is 13,869³ miles.

The lower Mississippi River, that portion extending southward from Cape Girardeau, Mo., to the Gulf, a distance of 1,128 miles, flows in a bed composed largely of sedimentary matter deposited by the river itself, and is typically a river with unstable bed, with rapidly caving banks, and shifting bottom. Except where the river strikes one of the bluffs that are found at long intervals south of Cairo, most of which are on the left bank, the banks range in height from about 25 to 40 feet above extreme low water. As the river in times of flood rises to 40 or 50 feet above the low-water line, the banks as well as the low lands lying back of them are consequently subject to overflow. The Mississippi River at all times contains a varying amount of material held in a state of suspension or rolled along the bottom by the motion of the water. When the water in the river becomes unusually agitated, as at flood time, and bank erosion is going on rapidly, the amount of sediment is greatly increased. At an active rising stage the material carried past a given point is said to be equal to 1,000 tons a minute. Now when the amount of water in the river is too great to be contained within its natural banks it flows out over the adjacent lands, where its motion being arrested, the sediment is deposited. Naturally the greater portion of the sediment is dropped near the river bank and the finer and lighter particles are carried farther inland. Thus it comes that the lands nearest the river, by receiving this annual deposit, are slowly built up until they have become considerably higher than those farther toward the interior. This is especially noticeable in the St. Francis and Yazoo basins, where the slope and consequently the drainage, is away from the river instead of toward it as is the case with most rivers.

From St. Louis to the Gulf the river drops 380 feet in a series of alternately reversed bends. In the bends the current impinges on the con-

¹ Annual Report, Chief of Engineers, 1909, p. 2677.

² Annual Report, Chief of Engineers, 1909, p. 564.

³ Preliminary Report of Inland Waterways Commission, 1908, p. 35.

cave bank, causing a deepening of the water along the shore and, in most cases, rapid caving and erosion of the bank. At the foot of each bend the main flow crosses to the other side, impinging on the concave bank on that side, and so back and forth, the place in the channel where this takes place being called a "crossing." In these crossings the current slackens and there results a local deposit of the rolling or suspended material moving with the water which deposit forms a "bar." Thus it happens that there is a shoaling of the river with a bar of some dimensions between every two bends in the river as well as at any point of a straight reach where the river is unusually wide. Some of the bars are not built up sufficiently to obstruct navigation or deflect the current noticeably, while others spread over large areas and rise to within a few feet of the water surface. The bottom of the river, if exposed to view, would show a succession of great sand hills and intervening depressions. It is the tops of the sand hills that form the bars obstructing navigation, and in order to provide navigable depths during periods of low water, the Government maintains a fleet of 10 or 12 powerful hydraulic dredges that cut channels through the bars, discharging the dredged material outside of the channel through a pipe line. These dredges operate between St. Louis and Vicksburg during the low-water months and usually maintain navigable channels throughout the year, except when the river is closed by ice.

The greatest and most fertile portion of the alluvial lands along the Mississippi River between Cape Girardeau and the Gulf being below the level of the flood, the first object of the planter has always been to secure himself against inundation in times of high water. To obtain this immunity the only practical method that has so far suggested itself is to raise the banks high enough to hold all the water and keep the river within certain permanent and prescribed limits. Thus the system of artificial embankments or "levees" as the French called them, came into use at a very early day, and the same system, though greatly improved as regards construction, prevails at the present time. The use of the levee as the sole method of restraining the waters of the Mississippi for the protection of the alluvial lands against the ravages of floods has been in practise since the year 1718, when the first settlement at New Orleans being greatly harassed by high water, began the construction of a levee about 3 feet in height in front of the town. By 1752 levees had been built along the river front 20 miles below and 30 miles above New Orleans. These levees were built by the planters themselves, each building a levee the length of his river front. In 1743 an ordinance was promulgated requiring the inhabitants to complete their levees by the 1st of January, 1744, under penalty of the forfeiture of their lands to the crown. Work progressed slowly up the river during the French and Spanish occupation and even after the Louisiana Purchase in 1803. In 1812 the levee extended a length of 155 miles on the east side of the

river and about 185 miles on the west side. The total length of the levees in 1812 was therefore 340 miles, and it is said that the amount expended in this work was between five and six million dollars. By the year 1828 the line of levees was continuous from Red River Landing to 65 miles below New Orleans, a distance of 260 miles.⁴ With the view of aiding the several States bordering the river in the construction of protection levees, the Federal Government in 1850 issued by grant certain swamp lands, which were to be sold by the States and the funds obtained thereby to be applied to levee work and drainage. Though many of these lands were of no commercial value at the time and could not be sold, a considerable sum of money was realized, and for a time levee construction went on at a rapid rate. The levees, however, were of low grade and inferior construction, and consequently proved of little avail when tested by the great flood of 1858, which carried away the greater portion of the embankments north of the mouth of Red River.

At the outbreak of the civil war the levees in the Yazoo district were fairly continuous, but of too low grade to offer much protection, except during moderately high water, and by the time hostilities ceased there was little left to show that levees had ever existed.

The great flood of 1882, which inundated the entire delta, directed forcible attention to the necessity for united and organized effort toward controlling the flood waters. For the purpose of closing the many crevasses made by the flood of that year, an allotment of \$1,300,000 was made from the funds appropriated by Congress in the River and Harbor Bill of that year for the improvement of the Mississippi River, which was the first allotment ever made by the Federal Government for levee purposes. Following this, small allotments were made for certain repairs in the levees made necessary by the succession of floods in 1883 and 1884. These allotments for repair of levees and subsequent allotments for construction and maintenance of levees were made by the Government for the purpose of improving the navigation of the stream, acting in accordance with the theory that the construction of levees would restrain the water in times of flood within a narrow space and that the additional force given by the weight of the water, together with the increased rate of flow, would tend to scour the channel and thus prevent the formation of sand bars by the deposit of sediment. This theory which led to the adoption of the plan for concentration of the waters of the river into one channel of an approximately uniform width, had been successfully applied in the opening and keeping open a deep channel through the South Pass of the Mississippi River from the head of the passes to the Gulf, and the success attained in that undertaking led to the belief that the same theory if applied to the entire river would deepen the channel.

⁴ *Riparian lands of the Mississippi River*, (Tompkins), p. 140.

The question of how much land the "combined" levee system would be required to protect from the river to the point where Saguenay Falls said:

"The only way to protect the entire length of the Mississippi River from the Gulf of Mexico is to build a levee system of 9,000 miles. This can be done by building a levee system of 9,000 miles, and the amount of land on each side of the river will be a large amount and will be large."

The first step taken was the creation of a permanent commission to be known as the Mississippi River Commission, and the act creating the commission was passed by Congress in June 1879. This commission submitted a report in the year 1880, recommending that to be followed in the permanent improvement of the lower Mississippi River, the recommendations of the report were adopted by Congress as the project for the permanent improvement of the river.

The plan of the Mississippi is divided into a number of subordinate basins, each in a measure independent of the others, so that the task of protection against floods was made simplified by reason of the fact that it did not necessarily require a vast and simultaneous organized effort of any kind. The system was one that could be undertaken in detail. Above the mouth of the River there are four great basins, drained separately by the St. Francis, the Yazoo, the Tennessee Bayou, and the Mississippi and their tributaries. All of these are now leveed, although the nearest approximation to a complete system has been made on the Yazoo front. The St. Francis Basin is a great oval plain with the Mississippi River from Cape Girardeau, Mo., forming its eastern boundary and a ridge of low hills, known in different places along the line as Hickory Ridge, Bloomfield Ridge, and Crowleys Ridge, forming its western one. Its greatest length is 215 miles, and it has an average width of 25 miles. From Commerce, Mo., to the lower end of the basin at Helena, Ark., the right bank is low, except at New Madrid, Mo. The upper portion of the St. Francis Basin is mostly hilly, while the lower and much larger portion is low and swampy with numerous lakes and bayous. This part of the basin slopes away from the river, and it also has a southern slope of 0.7 foot per mile. The basin is drained by the St. Francis River, which flows southward near the foot of Crowleys Ridge, and meets the Mississippi about 9 miles above Helena.

The Yazoo Basin is also an oval plain, and, like the St. Francis, slopes away from the Mississippi, a fortunate circumstance in connection with the construction of protection levees, as there are no streams emptying into the Mississippi for which openings were necessary. The eastern boundary of this great basin is a line of low hills along the base of which flows its principal drainage stream, known in its upper reach as the Coldwater River and toward its confluence with the Mississippi as the Yazoo. This stream is navigable for about 240 miles from its mouth.

The northern limit of the basin is near the Tennessee-Mississippi line. Here it is quite narrow, but farther south it widens out to a width of about 70 miles and then narrows again near the lower end at the mouth of the Yazoo. Its greatest length is 180 miles, and with the exception of a low ridge from 2 to 6 miles in width, an extension of Crowleys Ridge in Arkansas, which crosses the bottoms, the whole region is liable to overflow during times when the Mississippi is in flood.

The Tensas Basin extends from near the southern border of the St. Francis Basin to the mouth of Red River, its eastern boundary being the Mississippi River. The banks and the land generally are low and similar in character to those of the St. Francis and Yazoo basins, except that the Arkansas and White rivers find an outlet into the Mississippi, a fact which seriously interfered with levee construction.

The swamps in this basin are drained by Bayou Tensas, which unites with the Ouachita and Little rivers to form the Black, the most important tributary of the Red. The work of permanently closing this basin was commenced in 1888 and most of it was done after 1890. In 1897 the basin had been inclosed by a levee of an average height of 12 feet, but even then the flood overtopped the levee in many places, and several crevasses occurred. At the present time the levee in front of the Tensas Basin extends in an unbroken line from the high ground near Helena to the mouth of the Arkansas River and from near the mouth of the Arkansas to about 8 miles above the mouth of Red River.

Between Cape Girardeau, Mo., and Vicksburg there are five or six levee districts, organized under the laws of the various States, each with a separate board and corps of engineers, having control over the location and construction of levees along the front of the district, settling questions of rights of way, etc. The Federal Government, acting through the Mississippi River Commission, cooperates with the local levee authorities to some extent by allotting for levee work a portion of the funds appropriated by Congress for the general improvement of the river, which funds are expended in constructing on rights of way donated by the local levee boards, new levees where necessary to preserve the continuity of the line, in raising and enlarging old levees to a standard grade, and in assisting the local authorities in preserving the levees during flood periods.

The upper St. Francis levee district extends from the high lands at Commerce, Mo., to New Madrid, Mo., a distance of 85 miles. The levee is now built from about 20 miles above Cairo to about opposite Hickman, Ky., and though a line from that point to New Madrid has been proposed, the work is still held in abeyance on account of the difficulty in settling the question of drainage. In that section of the district several small rivers and bayous draining that portion of the State empty into the Mississippi and, until a means is provided for taking care of the surface water, this stretch of about 30 miles will remain

open. On the left bank of the river a line of levees now runs from Hickman, Ky., to the foot of Donaldsons Point, which is about opposite Point Pleasant, Mo., the northern end of the lower St. Francis levee system. The purpose of this levee is to restrain the overflow water from passing into Reelfoot Bottom and flooding Lake County, Tenn., and other sections in that vicinity.

The lower St. Francis levee district extends from Point Pleasant, Mo., to Helena, Ark. Formerly when the Mississippi between Cairo and Memphis reached a stage of 25 or 30 feet, the water would spill over the low banks and back up the numerous bayous until the swamps and low places were filled. Then as the river rose still higher, the surplus water would flow uninterruptedly over the land to the westward and enter the St. Francis River through which it found its way to the main stream at Helena. The purpose then of the St. Francis levee is to compel the flood waters in the Mississippi River to follow their natural channel instead of flowing out over the land. Levee construction in the lower St. Francis district began soon after 1850, and by 1858 a somewhat broken line of embankments extended from the high lands below New Madrid, Mo., to near the lower end of the basin. These, however, as before stated, were of little avail against floods and most of them were soon destroyed. Nothing further was done toward an organized movement to close the basin until 1893, when the first St. Francis Levee Board was formed, and the Government began to make yearly allotments for levee work. When the great flood of 1897 occurred the St. Francis levee only extended as far south as Pecan Point, a distance by river of about 125 miles. This line was made up principally of the old State levee above referred to, which had been enlarged and strengthened, but when put to test by the flood was found too small and upon the whole quite inadequate to effect the object intended. While this levee in a measure resisted the ravages of the flood in some places, there were 23 serious breaks in 1897, mostly in the lower portion of the line, and as a result the country received very little protection. Six years later, in 1903, this line of levee had been extended southward as far as Cat Island, below Memphis, a total length of 173 miles. The whole line had been practically rebuilt when the flood of 1903 occurred and in that year there were only two breaks, notwithstanding that the water was much higher than in 1897.

The present length of the lower St. Francis levee line is 202.5 miles, which added to the upper St. Francis line, comprising 47.5 miles, gives a total of 250 miles of levee on the right bank of the river above Helena. Below Helena on the right bank of the river, the White River district has 74 miles, upper Tensas 190.6 miles, lower Tensas 153 miles, a total of 417.6 miles, which added to the 250 miles in the St. Francis system gives a total of 667.6 miles of levee on the right bank above the mouth
Red River.

The St. Francis levee has an average height of 16 feet, with a base 104 feet and a crown 8 feet in width, topped by a curved section with a 3-foot crown. The levee of course varies in dimensions according to the level of the location upon which it is built, but it is believed to be sufficient to hold a volume of water equal to that of 1882. The work already done in this district alone has cost the people of the St. Francis Basin \$2,500,000, in addition to about \$2,000,000 allotted by the Federal Government. The work yet to be done in order to bring the St. Francis levee system to the ideal proportions will probably increase the total expenditure to near \$7,000,000. The great value of this levee to the country will be the reclaiming of 2,240,000 acres of the richest and most productive soil in the world.

The Yazoo Levee Board was organized in 1884. At that date the levees were insignificant, both in height and other dimensions and of very inferior construction as compared to present levees. They had been long neglected and in some places there was little to distinguish them from the natural ground. They could therefore afford little or no protection against a flood. The upper Yazoo levee district covers a distance of 124 miles and extends from the northern line of the State of Mississippi, near Horn Lake, to the southern boundary line of Bolivar County. The lower Yazoo district extends from the Bolivar County line to near the mouth of Yazoo River, a distance by river of about 230 miles. The length of this line of levees is 188 miles, making in all 312 miles of levee in the State of Mississippi. These levees are practically complete and are considered sufficient to withstand the highest water.

In 1882 the lower Yazoo levee line was very irregular in grade, with an average height of only about 7 feet and broken by extensive gaps. In that year or immediately following the great floods of 1882 and 1883, the real work of constructing a levee on something approaching modern lines began, and the work progressed so well that in 1884 there was but one crevasse in the entire line. After this no break occurred in the lower Yazoo district until 1890, when there were six, and again in 1891 when one break occurred. In 1897 occurred the greatest overflow ever experienced in the lower valley; the levee in this district broke in five places, and one very serious crevasse occurred in the upper district, making six in all. In 1903 one break occurred in the lower district, but since that year the levees have withstood all floods.

On July 1, 1908, there were 1,486 miles of levee along the river south of Cape Girardeau, Mo., not including those on the tributary streams. Since that time some extensions have been made and many miles of new levee constructed to replace those that were located too near the river, or upon unstable foundations. One of the many serious problems confronting the levee builder is that of caving banks. These encroachments of the river, which most often take place in the bends, frequently *bring about changes in the course of the river and annually destroy many*

miles of expensive levees which must be replaced by new ones built farther back from the river. In certain of the bends of the river as many as five lines of levee have been built in the past thirty years and as long as these conditions exist, a strictly permanent levee system is impossible. Again, the ever-increasing elevation of the flood planes, due to additional constrictions of the flood volume by the extension of new lines of levees, renders the establishment of permanent levee grades extremely difficult, if not impossible, until they are brought to an actual test under the newly-developed conditions. The flood of 1897 found the river in the Yazoo district leveed on both sides for the first time in history, and the effect of this was a filling of the depressions, the establishment of a new flood plane in accordance with the changed conditions, and a disturbance of gage relations at all points above Helena. In this way, new grades that have been established at various points in the St. Francis system, in accordance with the changed conditions due to the presence of levees on the left bank of the river, have raised the flood plane above the original estimates, and as a result a vast amount of enlargement work has been required. These enlargements and the building of new loops around badly-constructed or improperly-located levees constitute the principal work at the present time.

The total amount expended by the Federal Government on levee work below Cairo to July, 1908, was something over \$23,000,000, and, while the amount expended by the different States is not known, it is supposed to have been in the neighborhood of \$30,000,000. The area protected by these levee systems is approximately 27,000 square miles or about 17,300,000 acres.

EFFECT OF LEVEES ON FLOOD STAGES.

In former times the effects of a rise in the river upon the swamp lands began to appear when the rising water attained the level of the bed of the connecting bayous, that is, when the surface of the river was still 10 or 15 feet below the top of the natural banks. The first effect was to stop the discharge of these bayous and to accumulate rainwater in the swamps. As the Mississippi rose to still higher levels a considerable volume of water was poured into the bottoms through the numerous bayous and other outlet streams, and as a result the swamps and low places were often well filled before the river even reached a bank-full stage.

Since the levees, as now constructed, close these bayous and exclude the Mississippi water from the swamps, their effect on the river become apparent to some small extent with stages as low as 25 feet, becoming more and more pronounced as higher levels are reached. The ground usually being higher near the edge of the bank than at the base of the levee, a flood which only partially covers the ground in the vicinity of *the bank, often puts several feet of water against a levee that has been*

built some distance back from the river, while one built on the immediate bank is entirely free from water.

It is probable that the levees constructed previous to 1871 from Cape Girardeau to Vicksburg had the effect of increasing the height of the flood plane in certain reaches of the river, but, owing to the lack of continuity in the line of levees and the absence of comparable stage data, it is not possible to even approximate the changes in the river regimen until a much later date.

In 1871 river gages were established at several places along the river and daily observations of the height of the river became a part of the duties of the Weather Bureau observers at all river stations. This was the beginning of a systematic daily survey of the river fluctuations that has continued without change or interruption to the present time. The Mississippi River Commission was created in 1879, and soon thereafter the course of the Mississippi was accurately surveyed and its slope determined by precise levels. Additional river gages were also established at that time, so that since 1880 the daily stages have been recorded at intervals of about 50 miles or less along the entire course to New Orleans.

The zero point on the Mississippi River gages usually represents the lowest level the surface of the water had reached at the time the gage was established, but in many instances the water has since gone below this mark. The elevations of gage zeros are referred to the mean Gulf level at Biloxi, Miss. That is, the elevation of the zero of the gage at Cairo is 270.9 feet above mean Gulf level, Memphis, 184.1 feet, Helena, 142.1 feet, Greenville, 88.5 feet, Vicksburg, 46.2 feet, Natchez, 17.1 feet. Thus the zero elevations of the various gages give approximately the low-water plane of the river. An approximate relationship exists between the gage readings on the Mississippi when normal stages prevail, and if the natural banks were sufficient to hold all the water that passes Cairo this relationship would be fairly constant, except when disturbed by heavy discharges from tributary streams. But, through the overflowing of banks and the consequent loss of water to the swamps, the crest of a rise loses its identity and the relation between the gages is seriously disturbed. The occurrence of a crevasse at any point in the line of levees has the same effect on all gages located between the point of the break and the foot of the basin.

Since 1882 the conditions affecting the flood regimen in this reach of the river have materially changed by the extension and enlargement of the levees, and during the twenty years ending with the year 1903, they have undergone an annual change so that rules established in one flood year could not be successfully applied to the one following, no two being exactly alike. However, with stages of 30 feet or under at Cairo the relation between the gages is probably very near what it was in 1871; in fact, the records show very little change.

Levees have no marked effect on river stages, except when the river is out of its banks or rises sufficiently high to cause a considerable amount of water to back up the tributary streams where such exist. In this reach of the river (Memphis) there is very little loss of water unless the river reaches a stage of about 25 feet at Memphis.

As all great floods emanate north of Cairo the gage at that place is accepted as an index to what will follow at points below.

The difference between Cairo and Memphis, with Cairo reading 20 feet or less, is from 5 to 7 feet and for stages up to 30 feet at Cairo the difference is approximately 7 feet, Cairo reading the higher. These were the gage relations in 1872 and they are practically unchanged at the present time. Previous to 1896 when the water during flood periods was unrestrained by artificial embankments, the difference between Cairo and Memphis increased in proportion to the height of the flood wave, while under the changed conditions south of Cairo, the tendency during extreme high water is for the two gages to come closer together. Formerly a 46-foot stage at Cairo gave Memphis 35 feet, which was the maximum at the latter place up to 1897, when the levees first began to show their effect. The highest stage on record at Cairo is 52.3 feet, which occurred in 1883, and the resultant stage at Memphis was 35 feet, or the same as is now shown by a 46-foot stage. This indicates that there was a loss due to overflow water passing into the bottom lands of about 7 feet. The difference between Cairo and Memphis in 1882, 1883, and 1884, when the stage at Cairo reached the extreme height of 52 feet, was 17.5 feet. In 1897, with an imperfect levee fronting only about one-third of the St. Francis Basin, the difference was reduced 3 feet. In 1903, with a still incomplete levee and two serious breaks a few miles above Memphis, the difference was only 10.6 feet, a reduction since 1897 of about 4 feet, and since 1884 of about 7 feet. In 1907, by reason of the further extension and enlargement of the St. Francis system of levees, a further increase in the flood level at Memphis is shown. In that year the difference between the Cairo and Memphis gages was exactly 10 feet, showing that the flood plane at Memphis had been raised 7.6 feet since 1884, and that this increase was brought about by confining the water to narrower limits through the extension of the Arkansas levee along the right bank of the stream. It should be borne in mind that notwithstanding the abnormal stages below Cairo in 1903 and 1907, the actual volume of water coming into the valley was much less than in either 1882 or 1884 and decidedly less than in 1897. Not only was the stage at Cairo 1 foot below the record for the years named, but the wave was much shorter. At Cairo in 1882 the water was above a 40-foot stage on 81 days, above 45 feet on 56 days, and above 50 feet on 9 days. In 1907 it was above these stages on 34, 16, and 4 days, respectively.

Since 1907 a line of levees has been constructed in Scott County, Mo., from the high ground at Commerce, Mo., to the west end of Big Lake,

about 15 miles west of Cairo, where it joins the Mississippi County levee and forms a continuous line to below Island No. 5. The closing of this reach of 15 miles will, in times of overflow, prevent the water from flowing out over Scott County, Mo., to the tributaries of the White and the St. Francis rivers, by which they were formerly carried southward to join the main stream at Helena and below. Another factor having a material effect on the gages at New Madrid and Memphis is the new line of levees on the left bank running from Hickman, Ky., southward to near Tiptonville, Tenn., but as this levee has not yet been built to the standard grade, its effect during extreme high water is uncertain. As the highest water that has occurred since 1907 is over 5 feet below the extreme stage, it is difficult if not impossible to accurately determine the final effect of these recent levee extensions on the river below Cairo, but at the highest stage in 1909, 47.3 feet at Cairo, an increase in the flood plane is noted at both New Madrid and Memphis. The increase at New Madrid certainly amounts to 2 feet, while at Memphis it is probably somewhat less. It is reasonably certain, however, that a flood equal to those of 1883 or 1884 would give Memphis at least 43, and possibly 44 feet, provided there were no breaks in any of the levees. Table 1 gives the maximum stages at different points along the river during the three great floods that have occurred since 1882, and also during the year 1909, and shows the changes in the gage relations to the present time; also the expectations regarding future floods based on the water of 1882:

TABLE 1.

Stations.	1882.		1897.		1903.		1907.		1909.		Expectation based on 1882.
Cairo.....	51.8	.....	51.6	.....	50.6	.....	50.4	.....	47.3	.....	.....
New Madrid.....	41.5	-10.3	40.3	-11.3	39.5	-11.1	39.3	-11.1	38.6	- 8.7	44.0
Fulton.....	36.7	-15.1	37.5	-14.1	40.2	-10.4	38.4	-12.0	35.5	-11.8	41.0
Memphis.....	35.2	-16.6	37.1	-14.5	40.1	-10.5	40.3	-10.1	38.6	- 8.7	43.5
Helena.....	47.2	- 4.6	51.8	+ 0.2	51.0	+ 0.4	50.4	± 0.0	47.7	+ 0.4	52.0
Arkansas City.....	47.0	- 4.8	51.9	+ 0.3	53.0	+ 2.4	52.1	+ 1.7	50.1	+ 2.8	55.0
Greenville.....	41.7	-10.1	46.8	- 4.8	49.1	- 1.5	47.3	- 3.1	44.8	- 2.5	51.0
Lake Providence.....	38.3	-13.5	44.5	- 7.1	46.5	- 4.1	46.3	- 4.1	44.4	- 2.9	48.0

All changes are computed from the maximum stages at Cairo.

The estimates here made are based on data taken from the early spring rises only. At such times the ground is well saturated and the swamps and tributary streams more or less full of water, and as a result a flood wave coming into the valley produces its maximum effect. Later in the spring or during the early summer months, with a deficient moisture supply in the ground, and with the streams low, a given stage at Cairo will give lower resultant stages at all points below. Again, the crest stage is affected to a considerable extent by the condition of the White and Arkansas rivers. This is particularly noticeable at *Helena and Arkansas City*. With those rivers in flood, or when the

lower Mississippi is abnormally high, the slope is somewhat decreased and consequently the run-off is checked to an extent sufficient to cause the Helena gage to show a higher stage with reference to Cairo than would be the case if the lower rivers were low and the slope normal. Under the latter condition it is possible for a 45-foot stage at Cairo to give 35 feet at Memphis and 44 feet at Helena, and corresponding stages at points below. However, under favorable flood conditions, the Memphis gage will show from 8.5 feet to 9.5 feet less than Cairo on stages exceeding 40 feet at the latter station. The difference between Cairo and Helena for stages under 35 feet is about 1.5 feet, that is Helena will be that much below Cairo, while the difference at Memphis is from 7.5 to 8 feet.

EFFECT OF LEVEES ON THE RIVER SOUTH OF MEMPHIS.

Helena, Ark., being located at the lower end of the St. Francis Basin, the gage at that place was formerly affected to a considerable extent by the return flow of the waters that had escaped from the main stream between Cairo and Memphis. It has been estimated that this return flow, which usually occurred about the time the flood crest reached Helena, had the effect of raising the stage at that place about 3 feet. That it prolonged the flood at Helena there is no room for doubt, as will be seen in another portion of this report. Mr. H. N. Pharr, Chief Engineer of the St. Francis Levee Board states in this connection as follows:

The return flow from the St. Francis Basin at Helena has the effect of raising the water on that gage at least 3 feet above what it would do if the basin had been closed. An idea of the quantity of support given the flood in the lower river may be had when it is stated that the area of the St. Francis Basin is about 5,000 square miles and the average depth is about 8 feet. Supposing the basin to be filled, as sometimes was the case, this water would equal a stream one mile wide, 1,000 miles long, and 40 feet deep. Flowing at the rate of 1,000,000 cubic feet per second, or an average velocity of 4.5 feet per second, it would take 14.5 days to run out. This is close to what, in fact, occurs.

The idea of building the St. Francis levee until those below were perfected, was strongly opposed by property owners along the lower river, the objection being based on the supposition that closing the basin would raise the flood height at Helena and from there southward to the Gulf. Engineers, at least many of them, held to the opposite opinion, and some went so far as to say it would lower the flood at Helena and possibly at points below.

Colonel Suter of the United States Engineer Corps gave it as his opinion that---

In a general way it has been shown that the large increase in the flood height has been mainly confined to intermediate points along the great swamp basins. At the lower end of these basins the change has been slight, as for instance, Vicksburg. The
on' of the uncertainty which now remains is the effect of leveeing the St.

Francis Basin. That will increase the flood height at Memphis and all points above seems certain, but so far as concerns the river below Helena there is much to be said. All the water which now reaches the main stream above the junction with the White River now passes Helena between levees, and hence has produced its maximum effect.

During the great floods of 1882, 1883, and 1884, the maximum stages at Helena and their relations to the Cairo gage were substantially the same, that is to say, Helena had 47 feet against 52 at Cairo, a difference of 5 feet. At that time there were no levees on the Arkansas side of the river, and those on the left bank were not sufficient to hold the water at flood stage. By 1886, however, the Mississippi state levee had been enlarged; the crevasses that were made during the great floods that occurred after 1882 were all closed, and, although the river reached a stage of 48.1 feet, no break occurred. This was 1 foot higher than ever before known at Helena, notwithstanding the fact that Cairo was 1 foot below its maximum. This would indicate that the levee was responsible for an increase in the flood height of 2 feet.

The next extreme high water occurred in 1897, and at that time there was a good, strong levee on both sides of the river in the vicinity of Helena, but otherwise the conditions were about the same as when the floods above mentioned occurred. The maximum stage at Helena was 51.8 feet, or nearly 5 feet above the previous record, while Cairo was still a fraction of a foot below the extreme flood stage. A higher maximum would probably have been shown had it not been for the great Flower Lake crevasse, which occurred on the opposite side of the river, a few miles above Helena on April 3, and diverted an immense body of water to the swamps of Mississippi. At the time the crevasse occurred the river was rising steadily at the rate of three or four-tenths of a foot daily, so it is reasonable to suppose that, if the levee had held, Helena would have experienced a stage exceeding 52 feet. At this time the St. Francis Basin was only leveed from Point Pleasant, Mo., to Pecan Point, Ark., and even that offered but little resistance to the flood.

In 1903 the St. Francis levee extended only to Cat Island, a few miles below Memphis, and from there to the foot of the basin there was no levee protection whatever. In addition to this there were two serious crevasses a few miles above Memphis, so that the lower portion of the basin was about as deeply flooded as in former years when there were no levees at all. This being the case the gage relation between Cairo and Helena that obtained in 1897, was not disturbed, both recording practically the same stage.

The first real test regarding the effect at Helena came in 1903. The St. Francis levee system was complete from the high ground in Missouri to the mouth of the St. Francis River and the whole line, both above and below Helena, was intact. Referring to Table 1 it is seen that Helena still follows Cairo very closely, and the two gages have the same relation *to each other as in 1897 and 1903*. Thus the contention that the St.

Francis levee would not raise the flood level at Helena is to some extent verified. The fact remains, however, that there is a fairly permanent ratio of unity between Cairo and Helena at an overflow stage, and the contention of some eminent engineers that the extreme maximum at Helena would not exceed 49 feet does not appear to be well founded. That the St. Francis levee did not raise the flood level at Helena is due to the fact that the return flow from the basin has been eliminated and this offsets whatever effect the restraint offered by the levee may have had.

While the complete closing of the St. Francis Basin has had the effect of giving increased stages at all intermediate points it is seen by Table 2 that it has also had the effect of materially shortening the duration of the floods at Memphis and Helena as well as at some points below:

TABLE 2.—Number of days above flood stage.

Year.	Cairo.	Memphis.		Helena.		Arkansas City.	Greenville.	Lake Providence.	Vicksburg.
	45 feet.	33 feet.	35 feet.	42 feet.	45 feet.	42 feet.	42 feet.	42 feet.	45 feet.
1892.....	56	65	6	79	48	108	0	0	39
1890.....	43	41	35	28	32	112	40	0	95
1897.....	47	55	45	66	45	72	45	42	70
1903.....	20	43	23	65	29	81	39	27	60
1907.....	16	30	16	33	19	59	31	29	33

At Memphis the river was above flood stage (33 feet) on 55 consecutive days in 1897, 43 days in 1903, and 30 days in 1907. At Helena it was above flood stage (42 feet) on 66 days in 1897, 65 days in 1903, and 33 days in 1907. In 1897 Cairo was above flood stage (45 feet) on 47 days, and above 50 feet on 15 days. In 1907 it was above 45 feet on 16 days, and above 50 feet on 4 days. It is true the volume of water in 1907 was not equal to that of 1897, but the difference in volume is not sufficient to account for the great decrease in the length of the flood period at Helena, that is, from 66 to 33 days. At Memphis the effect of the river as regards the run-off is not as noticeable as at Helena, but it is believed the flood period has been shortened at the former place, as shown by the rapidity of the fall in 1904 and 1907, as compared with previous floods. In 1907 it was not until 43 days after the arrival of the crest that the water fell below flood stage, while in 1904 it took only 10 days, and in 1907 only 9 days.

As floods in the lower Mississippi River usually occur during the planting season, the importance of hastening the withdrawal of the water from the land can not be overestimated. A difference of a few days may sometimes determine the fate of a crop. There are large tracts of rich tillable land lying unprotected along both banks of the river, as well as numerous island plantations that are more or less flooded each year. These overflows are expected, and, as a rule, are of great benefit to the

soil, as they leave a rich deposit on the land. The levees have caused these lands to be more extensively and more deeply flooded and in some individual cases have worked a distinct hardship to the people occupying them. At the same time, if the period of inundation is materially shortened by confining the river to its natural limits, this hardship is greatly mitigated, and, on the whole, the levees may prove a benefit even to the lands that have no protecting levee.

Below Helena the gage readings show an increase in flood planes from 1882 up to the present time. These changes are very pronounced at all intermediate points along the Yazoo and upper Tensas fronts, and the least noticeable at Vicksburg, which is located at the bottom of the basin. The greatest increases in the flood plane are seen at Lake Providence, La., Greenville, Miss., and Arkansas City, Ark., respectively. In 1883 Greenville was 11.8 feet below the Cairo gage, but in 1903 the difference had been reduced to 1.6 feet, an increase in the flood plane of 10.2 feet. At Lake Providence the effect of levee construction on the flood waters is even more pronounced, the increase at that place amounting to 12 feet. At Arkansas City, previous to 1897, the flood crest was usually about 5 feet below the Cairo reading, but in 1903 it was 2.2 feet above, an increase of about 7 feet since 1890.

The abnormal stage at Greenville in 1903 and the remarkable change in the gage relation between Greenville and Arkansas City has been extensively discussed by engineers and others, and various theories have been advanced as to the cause. When the levees were small they were built so as to follow very closely around the bends and points because the highest ground was usually found close to the river bank, and on many of the points the bank was so high that up to 1882 levees were unnecessary. Then the points were practically leveed in. This had the effect of causing the high-water channel to conform closely to the low-water channel. As the different basins on each side of the river began to be leveed and closed up, the high-water level rose higher and higher, making it necessary to increase the height of the levee. As this work is very expensive and the value of the land on the points is not always in proportion to the cost of maintaining a high grade levee, it was often found expedient to shorten the length of the levee line by building new levees across the necks and throwing out the long lines around the points. This was done in that crooked reach of the river extending from Catfish Point, which is about 10 miles by river above Arkansas City, to Leland, just below Greenville. The distance along the channel of the river is about 48 miles, but in a direct line it is only 10 or 12 miles. The old levee following closely around the bends was about 53 miles in length. This was replaced by one running in a more direct line and disregarding the bends, so that a saving was made of about 42 miles of levee. The effect of throwing out the old levees around the bends is to *give the flood water free sweep across the points instead of following*

around the channel of the river as formerly, the same as though a series of cut-offs had been made in the bends above Greenville, thereby giving a greater slope to the water and consequently a greater velocity.

The writer believes that the abnormal height at Greenville in 1903 was due in part to the fact that the levees on each side of the river converge a few miles below Greenville, so that the distance between them is only about $1\frac{1}{2}$ miles. This holds the water back and produces an effect similar to that which would be caused by a dam. At Arkansas City the distance between the Mississippi and Arkansas levees is 5 or 6 miles, and below the gage the distance ranges from 10 to 15 miles. It is probable that the increased slope and consequent increased velocity given the overflow water in passing across the points, as above explained, throws a larger volume of water into the narrow space between the converged levees below Greenville than would be possible if the water had followed the natural channel of the river. The average difference in slope between Arkansas City and Greenville, comparing maximum gage readings for the years 1884, 1887, 1891, and 1898, is 5.32 feet. At the highest stage reached in 1903 the difference was only 3.9 feet, showing an abnormal rise at Greenville of 1.4 feet.

TABLE 3.—*Extreme stages during four recent floods in the Mississippi River compared to 1882.*

	1882.	1897.		1903.		1904.		1907.	
Cairo.....	51.8	51.6	-0.2	50.6	-1.2	49.1	-2.7	50.4	-1.4
New Madrid.....	41.5	40.3	-1.2	39.5	-2.0	37.5	-4.0	39.3	-2.2
Fulton.....	36.7	37.5	+0.8	40.2	+3.5	37.4	+0.7	38.4	+1.7
Memphis.....	35.2	37.1	+1.9	40.1	+4.9	39.0	+3.8	40.3	+5.1
Mhoons.....	39.8	41.6	+1.8	41.8	+2.0	40.3	+0.5	42.2	+2.4
Helena.....	47.2	51.8	+4.6	51.0	+3.8	47.7	+0.5	50.4	+3.2
White River.....	48.4	52.4	+4.0	53.7	+5.3	49.5	+1.1	51.9	+3.5
Arkansas City.....	47.0	51.9	+4.9	53.0	+6.0	49.0	+2.0	52.1	+5.1
Greenville.....	41.7	46.8	+5.1	49.1	+7.4	43.5	+1.8	47.3	+5.6
Lake Providence.....	38.3	44.5	+6.2	46.5	+8.2	42.5	+4.2	46.3	+8.0
Vicksburg.....	48.8	52.3	+3.5	51.8	+3.0	46.9	-1.9	49.7	+0.9
Natchez.....	47.8	49.8	+2.0	50.4	+2.6	45.6	-2.2	48.9	+1.1

TABLE 4.—Annual maximum river stages.

Year.	Caño.	Memphis.	Helena.	Arkansas City.	Greenville.	Lake Providence.	Vicksburg.
1872.....	39.2	31.5	39.0	26	.....	35.2	39.5
1873.....	41.6	32.5	40.0	6	.....	36.1	40.6
1874.....	47.4	32.0	45.8	11	.....	37.4	45.7
1875.....	45.1	33.0	42.8	12	.....	37.3	43.0
1876.....	46.4	34.1	44.8	17	.....	38.0	44.9
1877.....	40.5	32.0	41.8	30	.....	35.8	41.6
1878.....	37.0	29.1	38.8	3	.....	35.8	41.0
1879.....	36.5	28.1	37.2	3	.....	36.0	40.4
1880.....	44.6	33.4	43.8	31	.....	38.0	43.4
1881.....	44.8	33.3	43.7	45.1	.....	38.2	43.2
1882.....	51.8	35.2	47.2	28	.....	36.2	41.8
1883.....	52.2	34.8	47.2	11	.....	36.5	43.8
1884.....	51.8	34.8	46.9	8	.....	38.4	43.0
1885.....	51.0	29.2	40.7	30	.....	35.5	42.4
1886.....	51.0	34.8	48.1	5	.....	37.9	44.2
1887.....	48.5	35.3	46.3	22	.....	38.0	44.2
1888.....	45.2	34.2	45.4	23	.....	38.1	44.2
1889.....	34.5	36.6	47.7	30	.....	39.4	44.2
1890.....	48.8	35.6	47.7	30	.....	39.4	44.2
1891.....	46.2	34.9	44.7	27	.....	41.0	44.1
1892.....	48.2	34.6	45.8	1	.....	41.0	44.1
1893.....	49.3	35.2	45.8	29	.....	41.9	48.4
1894.....	37.0	29.4	38.0	24†	.....	34.3	48.3
1895.....	33.3	24.0	31.2	32	.....	25.9	48.3
1896.....	39.2	29.5	38.4	1	.....	31.7	48.3
1897.....	51.6	37.1	43.8	19	.....	30.0	48.3
1898.....	49.8	37.3	43.1	29	.....	33.2	48.3
1899.....	36.2	35.3	46.0	15	.....	44.5	49.4
1900.....	32.1	32.1	48.6	23	.....	44.4	49.4
1901.....	43.2	30.8	41.6	39	.....	41.6	47.3
1902.....	50.6	39.0	48.1	12	.....	33.0	38.0
1903.....	49.1	40.1	45.0	25	.....	36.4	41.5
1904.....	38.6	29.0	37.8	28	.....	35.0	41.2
1905.....	46.9	37.0	47.0	3	.....	42.5	46.9
1906.....	50.4	40.3	50.0	22	.....	43.7	47.2
1907.....	45.6	35.6	49.9	8	.....	46.3	49.7
1908.....	47.3	38.6	47.7	28	.....	44.1	47.9
1909.....	52.2	40.3	51.8	53.0	.....	44.4	48.1
Extreme.....	52.2	40.3	51.8	53.0	49.1	46.5	52.3

NOTE.—Where the maximum occurred on more than one date the first only is given.

*Also on May 10.

†Also on March 29.

‡Also on March 30.



Bulletin No. 39.—W. B. No. 463.

Issued December 2, 1911.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.

A COURSE IN METEOROLOGY AND
PHYSICAL GEOGRAPHY.

BY

W. N. ALLEN.

INSTRUCTOR IN PHYSICAL GEOGRAPHY,
TACOMA HIGH SCHOOL, TACOMA, WASH.

Published under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

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1911.



LETTER OF TRANSMITTAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU, OFFICE OF THE CHIEF,
Washington, D. C., August 1, 1911.

HON. JAMES WILSON,
Secretary of Agriculture.

SIR: I have the honor to transmit herewith a paper entitled "A Course in Meteorology and Physical Geography," which has been prepared by Prof. W. N. Allen, of the Tacoma High School, Tacoma, Wash.

Most of this course treats of meteorology, to which the other portions are cognate and introductory. If published, it would be of value to the Weather Bureau, both indirectly by increasing the attention given to meteorology in our high schools and also directly by guiding the younger men of the service in their elementary studies. I therefore recommend its publication as Weather Bureau Bulletin No. 39.

Very respectfully,

WILLIS L. MOORE,
Chief U. S. Weather Bureau.

Approved.

JAMES WILSON,
Secretary.

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A COURSE IN METEOROLOGY AND PHYSICAL GEOGRAPHY.

SYNOPSIS.

ASTRONOMICAL.

I. SUBJECT MATTER.

A. SOLAR SYSTEM.

1. Bodies of solar system.
 1. Sun.
 2. Planets.
 3. Satellites.
 4. Asteroids.
 5. Comets.
 6. Meteors.
2. Diagram of solar system.
3. Formation of solar system.
 1. Nebular theory.
 2. Other theories.

B. EARTH AS PLANET.

1. Movements of earth.
 1. Rotary.
 2. Revolutionary.
 3. Systematic.
 4. Others.
2. Shape of earth—Proofs.
3. Measurements, etc.
 1. Circles.
 2. Latitude.
 3. Longitude.
 4. Zones.
 5. Axis.
 6. Time.
 7. Surveys.
4. Diagrams of earth.
 1. Earth.
 2. Change of seasons.

II. LABORATORY EQUIPMENT.

A. REFERENCE BOOKS.

- | | |
|-------------------------------|--------------------------------|
| 1. Story of the Solar System. | 6. Earth's Beginnings, Ball. |
| 2. Realm of Nature. | 7. Tarr's Physical Geography. |
| 3. Young's Astronomy. | 8. Dryer's Physical Geography. |
| 4. Moulton's Astronomy. | 9. Salisbury's Physiography. |
| 5. Newcomb's Astronomy. | 10. Solar System, Poor. |

B. APPARATUS, ETC.

- | | |
|-----------------------|----------------------------|
| 1. Rotator. | 7. Globes. |
| 2. Centrifugal hoops. | 8. Sun board. |
| 3. Governor. | 9. Astronomical board. |
| 4. Glass globe. | 10. Charts, drawings, etc. |
| 5. Tellurian. | 11. Mariner's compass. |
| 6. Stereopticon. | 12. Stereopticon slides. |

1. ATMOSPHERIC TEMPERATURE

I. SUBJECT MATTER.

A. ORIGIN, COMPOSITION, ETC.

- 1. Chemical substances.**
 1. Oxygen.
 2. Nitrogen.
 3. Carbon dioxide.
 4. Argon, etc.
- 2. Foreign substances.**
 1. Dust particles.
 2. Microbes.
 3. Water vapor.

B. CONDITIONS OF ATMOSPHERE.

- 1. Variation in heat or temperature.**
 1. Nature of heat.
 2. Source of heat.
 3. Communications of heat.
 1. Radiation.
 2. Absorption.
 3. Conduction.
 4. Reflection.
 5. Convection.
 4. Measurement of heat.
 1. Thermometers.
 1. Fahrenheit.
 2. Centigrade.
 3. Thermograph.
 2. Senses.
 5. Distribution of heat.
 1. Vertical distribution.
 1. Representation.
 2. Effects upon life.
 2. Horizontal distribution.
 1. Representation.
 1. Isothermal lines, July and January.
 2. Climate zones, winter and summer.
 2. Modifying influences.
 1. Land masses.
 2. Water masses.
 3. Character of surface.
 4. Winds and currents.
 5. Mountain slopes, etc.
 3. Effects upon life.
 3. Periodical variations.
 1. Representation.
 1. Daily thermal lines.
 2. Yearly graphic lines.
 2. Extreme variations.
 3. Modifying influences.
 4. Effects upon life.

II. LABORATORY EQUIPMENT.

A. REFERENCE BOOKS.

- | | |
|-------------------------------------|--------------------------------|
| 1. Davis's Elementary Meteorology. | 6. About the Weather. |
| 2. Waldo's Elementary Meteorology. | 7. Tarr's Physical Geography. |
| 3. Realm of Nature. | 8. Works on Physics. |
| 4. Story of Atmosphere. | 9. Dryer's Physical Geography. |
| 5. Moore's Descriptive Meteorology. | 10. Salisbury's Physiography. |

B. APPARATUS.

- | | |
|-------------------|-----------------------------|
| 1. Ball and ring. | 6. Maximum thermometers. |
| 2. Circulation. | 7. Minimum thermometers. |
| 3. Convection. | 8. Fahrenheit thermometers. |
| 4. Conductometer. | 9. Centigrade thermometers. |
| 5. Stereopticon. | 10. Stereopticon slides. |

II. ATMOSPHERIC PRESSURE.

I. SUBJECT MATTER.

1. Height, weight, etc.
2. Means of determining pressure.
 1. Barometers.
 2. Barographs.
 3. Air pumps.
 4. Inverted glass.
3. Distribution of pressure.
 1. Vertical distribution.
 2. Horizontal distribution.
 1. East and west.
 2. North and south.
 3. Periodical distribution.
 1. Daily—Diurnal.
 2. Seasonal—Annual.
4. Representation of pressure.
 1. Barometric lines.
 2. Barometric sheets.
 3. Words "High" and "Low."
5. Movements of pressure.
 1. East and west.
 2. North and south.
6. Relations of pressure to:
 1. Weather conditions.
 2. Temperature changes.
 3. Effects upon life.

II. LABORATORY EQUIPMENT.

A. REFERENCE BOOKS.

- | | |
|-------------------------------------|-------------------------------|
| 1. Davis's Elementary Meteorology. | 6. About the Weather. |
| 2. Waldo's Elementary Meteorology. | 7. Tarr's Physical Geography. |
| 3. Story of Atmosphere. | 8. Works on Physics. |
| 4. Realm of Nature. | 9. The Weather, Abercromby. |
| 5. Moore's Descriptive Meteorology. | 10. Salisbury's Physiography. |

B. APPARATUS, ETC.

- | | |
|------------------------|-------------------------|
| 1. Standard barometer. | 5. Charts, drawings. |
| 2. Aneroid barometer. | 6. Barometer tubes. |
| 3. Barograph. | 7. Air pumps. |
| 4. Stereopticon. | 8. Stereopticon slides. |

III. ATMOSPHERIC CIRCULATION.

I. SUBJECT MATTER.

A. RELATION TO HEAT AND PRESSURE.

1. Planetary winds.
 1. Northeast trades.
 2. Southeast trades.
 3. Return trades.
 4. Prevailing westerlies.
 5. Return westerlies.
 6. Circumpolar winds.
 7. Equatorial calms.
 8. Tropical calms.
2. Storms, cyclones, anticyclones, etc.
 1. Character and indications.
 2. Relations to barometer and thermometer.
 3. Movements, (1) rotary, (2) progressive.
 4. Weather conditions in storms.
 1. Northeast quarter.
 2. Southeast quarter.
 3. Southwest quarter.
 4. Northwest quarter.
 5. Distribution and paths of storms.
 6. Storm signals and warnings.
 7. Representation, weather maps.
 1. Local.
 2. National.
3. Special winds.
 1. Land and sea breezes, daily.
 2. Monsoons, India and Spain, seasonal.
 3. Mountain and desert winds.
 4. Hurricanes, typhoons, and tornadoes.

B. RELATION TO CLIMATE AND LIFE.

II. LABORATORY EQUIPMENT.

A. REFERENCE BOOKS.

- | | |
|-------------------------------------|--|
| 1. Davis's Elementary Meteorology. | 6. Realm of Nature. |
| 2. Waldo's Elementary Meteorology. | 7. Tarr's Physical Geography. |
| 3. About Weather. | 8. Dryer's Physical Geography. |
| 4. Treatise on Winds. | 9. Salisbury's Physiography. |
| 5. Moore's Descriptive Meteorology. | 10. Whirlwinds, cyclones, and tornadoes. |

B. APPARATUS, ETC.

- | | |
|-----------------------------|--------------------------|
| 1. Black globe (18 inches). | 4. Convection apparatus. |
| 2. Wind vane. | 5. Mariner's compass. |
| 3. Anemometer. | 6. Stereopticon slides. |

IV. ATMOSPHERIC MOISTURE.

I. SUBJECT MATTER.

1. Evaporation.
 1. Favorable condition.
 2. Practical importance.
 3. Relative and absolute humidity.
 1. Means of determining, instruments, etc.
 2. Relation to temperature.
 3. The "dew point" table.
 4. Effects in relation to life.
2. Condensation of moisture.
 1. Cloud forms:
 1. Primary and secondary forms.
 2. Formation and distribution.
 2. Fog forms.
3. Precipitation of moisture.
 1. Governing law.
 2. Controlling conditions.
 1. Convection currents.
 1. Thunderstorms.
 2. Low pressure.
 3. Volcanoes.
 4. Doldrums.
 2. Intercepting mountains.
 3. Intermingling winds.
 4. Land and sea breezes.
 5. Northerly winds, drifts.
 3. Distribution and quantity in—
 1. Wind belts.
 2. Storm zones.
4. Crystallization of vapor.
 1. Frost.
 2. Snow.

II. LABORATORY EQUIPMENT.

A. REFERENCE BOOKS.

- | | |
|------------------------------------|-------------------------------------|
| 1. Davis's Elementary Meteorology. | 5. "Snow Crystals." |
| 2. Waldo's Elementary Meteorology. | 6. Tarr's Physical Geography. |
| 3. "Cloud Forms," Sigsbee. | 7. Salisbury's Physiography. |
| 4. "Cloud Studies," Clayden. | 8. Moore's Descriptive Meteorology. |

B. APPARATUS, ETC.

- | | |
|-----------------|---------------------------------|
| 1. Rain gage. | 5. United States cloud charts. |
| 2. Hygrometer. | 6. Cloud photographs. |
| 3. Evaporators. | 7. United States storm signals. |
| 4. Condensers. | 8. Stereopticon slides. |

THE OCEAN.

I. SUBJECT MATTER.

- 1. Distribution of oceanic water.**
- 2. Surface temperature.**
- 3. Movements of the ocean.**
 - 1. Wind and storm waves.**
 - 2. The tides.**
 - 1. Periodicity and causes.**
 - 2. Kinds and illustrations.**
 - 3. Relation to planets.**
 - 4. Cotidal lines.**
 - 5. Relation to commerce.**
 - 3. Ocean currents.**
 - 1. Nature and causes.**
 - 2. Relation to winds and temperature.**
 - 3. Distribution and illustrations.**
 - 4. Effect upon climate.**
- 4. Relations to life.**
 - 1. Commerce.**
 - 2. Food supply.**
 - 3. Water supply.**
 - 4. Drainage.**
 - 5. Climate.**

II. LABORATORY EQUIPMENT.

A. REFERENCE BOOKS.

- | | |
|--------------------------------------|---------------------------------|
| 1. Physical Geographies. | 4. Geography of the Sea. |
| 2. Land and Sea. | 5. Ocean Tides. |
| 3. Pilot Charts, Tide Tables. | 6. Astronomy. |

B. APPARATUS, ETC.

- | | |
|-----------------------------------|------------------------------|
| 1. Demonstration on table. | 3. Charts, maps, etc. |
| 2. Stereopticon slides. | |

EXERCISE I. THE GLOBE.

I. DIRECTIONS, ETC.

- 1. Draw upon unruled paper colored globe about 4 inches in diameter from actual inspection of globe. (2) Incline globe toward right $23\frac{1}{2}$ degrees. (3) Use protractor to determine angles. (4) Read Realm of Nature, pages 78-80, or Moore, pages 69-74.**
- 2. Place upon drawing in proper positions following lines with names: (a) Axis, (b) equator, (c) tropics, (d) ecliptic, (e) meridians, (f) polar circles. (2) Test accuracy of work by comparing it with standard globes.**
- 3. Place upon globe names and widths in degrees of following zones: (a) North Frigid, (b) South Frigid, (c) North Temperate, (d) South Temperate, (e) Torrid.**

4. Determine following points from actual inspection of mariner's compass: (a) North, (b) south, (c) east, (d) west, (e) northeast, (f) southeast, (g) northwest, (h) southwest. (2) Name objects that are situated (a) north, (b) south, etc., of high school. (3) State direction of high school from home.

5. Record daily for month wind directions and conditions of sky, whether (a) clear, (b) cloudy, or (c) partly cloudy. (2) Use cross-ruled paper, mariner's compass, and wind vane upon roof. (3) Read Chapter IX, Salisbury, page 60, Realm of Nature, or Appendix F, Tarr. (4) Prepare summary. (5) Determine from charts where magnetic poles, north and south, are located. (6) Locate line of no variation in America.

II. WRITTEN REVIEW.

1. Define names in Nos. 2 and 3. (2) How is degree upon circle determined? (3) Upon what does length of degrees depend? (4) How do degrees of longitude differ in length from degrees of latitude? (5) Insert table, page 25, Dryer, and explain.

2. Compare inclination of earth's axis with (a) position of tropics, (b) polar circles, and (c) widths of Frigid and Torrid Zones. (2) Where would polar circles and tropics be located if earth's axis were inclined 45 degrees, 20 degrees, 10 degrees, or 0 degrees? (3) State widths of zones in each case.

3. State where vertical sun would shine continuously if earth were not inclined upon its axis. (2) Use globe suspended from axis and light to illustrate. (3) Define (a) latitude and (b) longitude. (4) State (a) from what lines latitude and longitude are reckoned and (b) greatest number of degrees in each. (5) Give approximate longitude, and latitude of this city.

4. Which way does earth rotate? (2) Give proofs. (3) How long does it take to rotate once? (4) Show by use of rotator and centrifugal hoops effects of rotation upon shape of earth. (5) Illustrate by means of light and globe effects of rotation upon distribution of sunlight and heat. (6) Show by use of globe relation between longitude and time.

5. Find approximate difference in longitude and difference in time between Tacoma and New York. (2) Use tellurian, or map, and read Salisbury, page 311. (3) Locate parallel 40 or 45 degrees north. (4) State near or through what cities line passes. (5) Locate upon map and make sectional diagram, 6 by 6 inches, of township 18 north and range 4 east; number sections. (6) Subdivide section 16 into quarters. (7) Locate in red upon diagram and describe in words northeast quarter of section 16. (8) How is land usually described in deeds and tax receipts? (9) Use map of State or United States.

6. State difference between "Magnetic north" and "Polar north." (2) About how many degrees and in what direction is "declination" of magnetic needle in this city? (3) State where line of no variation is located in America.

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Appendix A and B.
2. Young's Astronomy, Chapters III, IV.
3. Moulton's Astronomy, Chapter VI.
4. Salisbury's Physiography, Chapters IX, X.
5. Realm of Nature, Chapter IV.
6. Dryer's Physical Geography, Chapter I.
7. Story of Solar System, Chapter V.
8. Maps of State or World.

EXERCISE II. CHANGE OF SEASONS.

I. DIRECTIONS, ETC.

1. Draw upon unruled paper rectangular figure 3 by 6 inches lengthwise of page. (2) Divide figure into eight squares $1\frac{1}{2}$ inches each.
2. Construct upon rectangle an ellipse, by using diagonal of one square for radii of side arcs, and diagonal of two squares for upper and lower arcs. (2) Extend middle lines of rectangle to intersect ellipse.
3. Draw upon points of intersection globes $1\frac{1}{2}$ inches in diameter, to represent earth (a) at autumnal and vernal equinoxes, and (b) at winter and summer solstices. (2) Make globes similar to globe in exercise No. 1.
4. Locate sun near center of diagram. (2) See that globe leans $23\frac{1}{2}$ degrees toward right. (3) Make slanting and vertical rays of sun in red. (4) See that sun's rays touch earth in right latitudes. (5) Test accuracy of work by using tellurian or astronomical board.
5. Place upon globe circles and belts as in exercise No. 1. (2) Represent night by shading globe. (3) Letter principal points of diagram A, B, C, D. (4) Date each point to correspond with season represented. (5) Indicate directions of earth's movements by means of arrows. (6) See Moore, page 70, or Waldo, page 73.

II. WRITTEN REVIEW.

1. State difference between ellipse and circle. (2) What is meant by "Major" and "Minor" diameters of ellipse? (3) State upon which diameter earth is on June 21 and December 21. (4) What are terminal points of diameter called? (5) State which point is nearest sun. (6) Read Salisbury, page 810.
2. State which way earth leans in respect to sun in June and December. (2) State when earth is farthest from sun. (3) Explain why it is warmer at Cancer in June than in December. (4) Use tellurian to illustrate. (5) Measure astronomical board. (6) Read Salisbury, Chapter X.
3. How many degrees of earth is covered by sunshine at one time? (2) How far and in what direction do extreme slanting rays extend from vertical rays? (3) Test answers by comparing them with tellurian.
4. State definitely three conditions that cause change of seasons. (2) Test accuracy of statements by use of tellurian. (3) Explain why length of day and night varies.
5. State latitude of vertical and extreme slanting rays at A. (2) Name seasons at each tropic, and the equator at A, also (3) comparative length of day and night, and (4) condition of light at each pole at A. (5) Do likewise with B, C, and D in separate paragraphs.

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Appendix A and B.
2. Waldo's Elementary Meteorology, Chapter II.
3. Realm of Nature, Chapter V.
4. Moore's Descriptive Meteorology, Chapter VII.
5. Young's Astronomy, Chapter IV.
6. Dryer's Physical Geography, Chapter I.
7. Salisbury's Physiography, Chapter X.
- o Diagrams upon Wall.

EXERCISE III. SOLAR SYSTEM.

I. DIRECTIONS, ETC.

1. Draw full-page diagram showing (a) relative positions, (b) relative sizes of planets in solar system. (2) Indicate direction of movements of planets by means of arrows. (3) Use tellurian. (4) See Tarr, figure 8, for radii, also Yagg's Chart of Solar System.

2. Draw diagram showing relative size of planets. (2) Insert diameters in red. (3) See Story of Solar System, page 11, or Tarr, pages 4 and 5.

3. Make table, full width of page, showing following summary of facts relating to bodies in solar system.

General summary of solar system.

No.	Planet.	Density.	Dist.	Rot.	Rev.	Incl.	No. Sat.	Diam.	Etc.

4. Abbreviate items in summary wherever possible. (2) See Young, page 402, or Story of Solar System, page 182, for form of diagram and summary of facts.

5. Draw diagram showing inclination of each planet. (2) Draw in black with inclination axis in red. (3) Represent each planet by means of circle, 2 inches in diameter. (4) See Story of Solar System, page 9. (5) Use protractors.

6. Insert "Bode's Law" with full explanation beneath. (2) See Young, page 190, or Realm of Nature, page 84. (3) Note space between Mars and Jupiter by red circle in diagram No. 1.

II. WRITTEN REVIEW.

1. Name proofs that planets are spherical in form. (2) State probable cause. (3) Refer to experiments with rotator and accessories in Exercise I.

2. Name planets according to size. (2) See summary and diagrams. (3) Which planet is densest? (4) Which is least dense?

3. State observation between density of planet and its distance from sun. (2) See summary.

4. Name planets according to distance from sun. (2) See diagrams.

5. Explain "Bode's Law." (2) State wherein it seems to be deficient. (3) Refer to diagram of solar system.

6. State what is thought to be origin of asteroids.

7. What is your observation concerning direction of rotation and revolution of planets?

8. State whether planets rotate and revolve in same direction.

9. State difference between comets and meteors. (2) Planets and suns.

10. State observation concerning direction and inclination of planets. (2) State what inclination of axis has to do with (a) change of season, (b) length of day and night, and (c) width of zones.

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter I.
2. Tarr's Physical Geography, Appendix A.
3. Dryer's Physical Geography, Chapter I.
4. Moore's Descriptive Meteorology, Chapter IV.
5. Young's Astronomy, Chapter I.
6. Realm of Nature, Chapters V and VI.
7. Story of Solar System.
8. Salisbury's Physiography, Chapter X.

EXERCISE IV. NEBULAR HYPOTHESIS.

I. DIRECTIONS, ETC.

1. State briefly, in series of paragraphs, main features of nebular hypothesis.
- (2) See Young, page 336, and Realm of Nature, page 92.
2. Make series of drawings, about 4 inches in diameter, to illustrate nebular hypothesis. (2) Make each drawing with brief explanatory statements upon sheet of unruled paper. (3) See nebulae in references.
3. Write explanatory notes of each drawing upon ruled paper, immediately before or after drawings. (2) See drawings upon wall and illustrations of nebulae in Young's Astronomy, page 336.
4. State clearly in separate paragraphs purpose of following experiments: (a) Rotating hoops, (b) rotating governor, (c) rotating and revolving balls, and (d) rotating liquids in glass globe. (2) Make drawings of experiments to accompany each paragraph.

II. WRITTEN REVIEW,

1. Give some reasons why nebular hypothesis is generally accepted. (2) See Young's Astronomy, page 347.
2. Explain following facts regarding planets by means of nebular hypothesis: (a) Shape, (b) density, (c) movements, (d) composition, and (e) condition in respect to heat. (2) Mention experiments in connection with explanation.
3. Read what is said in reference books concerning "Nebulae." (2) Give brief summary of readings. (3) State what bearing observed nebulae have upon nebular theory.
4. State what seems to be chief cause in changing (a) gases into liquids or solids, (b) in producing spherical form of planets, (c) in separating bodies into parts. (2) Give illustration by referring to experiments.
5. State what is probable condition of moon. (2) What is likely to become of oceans and atmosphere of earth in time? (3) What will probably become of sun's heat? (4) Of life upon earth?

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter I.
2. Tarr's Physical Geography, Appendix A.
3. Dryer's Physical Geography, Chapter I.
4. Young's Astronomy, Chapters I, II.
5. Moulton's Astronomy.
6. Story of the Solar System.
7. Realm of Nature, Chapters V, VI.
8. Yagg's Charts.

EXERCISE V. THE ATMOSPHERE.

I. DIRECTIONS, ETC.

1. Give short description of origin of atmosphere. (2) State briefly what is likely to become of earth's atmosphere in time. (3) Read Story of Atmosphere, page 9, Davis, pages 2-8, or Moore, Chapter I.
2. Insert table, page 275, Dryer. (2) State beneath table three things table is designed to show. (3) State which substance in air is (a) lightest, (b)

heaviest, (c) most abundant, (d) most beneficial to plants, (e) most injurious to animals. (4) Mention effect of oxygen upon life. (5) Give brief account of nitrogen, its uses, etc.

3. Name five sources of dust particles. (2) Read references to dust. (3) State how dust is distributed through air. (4) Insert tables, page 24, Story of Atmosphere. (5) State what each table is designed to show. (6) Read Moore, pages 29-33.

4. Make colored drawing on unruled paper full length of page of prism and spectrum. (2) Test colors by comparing them with solar spectrum or colored disks. (3) Read Realm of Nature, page 36, and Story of Atmosphere, page 147. (4) Substitute raindrop for prism in drawing and draw rainbow. (5) Experiment with prism.

5. State effect of dust particles upon (a) color, (b) heat, and (c) light of atmosphere. (2) Explain (a) color of sky, and (b) twilight and dawn. (3) Read Davis, Chapter IV, or Tarr, page 119.

6. Discuss two classes of microbes. (2) State conditions under which microbes thrive. (3) Name some benefits and dangers of microbes. (4) Name some simple means of preventing microbes. (5) Read "Bacteria, etc.," by Conn, Waldo, page 9, or Moore, page 27.

7. Insert upon unruled paper figure 18, page 74, Waldo, or figure 253, page 277, Dryer, lengthwise of page. (2) Substitute Mount Tacoma for mountains in figure. (3) Make drawing three times size of figure in book. (4) State beneath figure, four things figure is designed to show.

II. WRITTEN REVIEW.

1. How would slight variation in quantity of oxygen or nitrogen affect life of animals? (2) Read Story of Atmosphere, or Moore, Chapter II.

2. Where is carbon dioxide most plentiful? (2) Was it ever more plentiful? (3) Give reasons for each statement. (4) Read Realm of Nature, page 263, and Story of Atmosphere, page 20. (5) Give brief account of some noted "Death gulch." (6) State briefly what makes such gulches dangerous. (7) Read Davis, pages 5-6.

3. Name five uses of dust particles. (2) Where is dust most plentiful? (3) State briefly chief uses and work of atmosphere. (4) Explain why water vapor floats in air. (5) See Table No. 1.

4. Define color. (2) Name seven prismatic colors. (3) Explain formation of (a) colored sunsets, and (b) rainbows. (4) Explain formation of spectrum and rainbow.

5. Account for presence of water vapor in air. (2) Mention its uses. (3) Does water vapor weight more or less than dry air? (4) Give some proofs.

6. State how nebular hypothesis explains origin of atmosphere. (2) Read Realm of Nature, pages 92-94, or Moore, Chapter IV.

III. REFERENCE BOOKS.

1. Story of Atmosphere, Chapters I, II.
2. Waldo's Elementary Meteorology, Chapter I.
3. Davis's Elementary Meteorology, Chapters I-IV.
4. Moore's Descriptive Meteorology, Chapters I, II, III.
5. Realm of Nature, Chapter VII.
6. Tarr's Physical Geography, Chapter XII.
7. Dryer's Physical Geography, Chapter XXII.
8. Salisbury's Physiography, Chapters XI, XII.

EXERCISE VI. HEAT.**I. DIRECTIONS, ETC.**

1. Read references to heat. (2) Keep for time end of wire in flame. (3) Test temperature of other parts. (4) Make drawings to illustrate experiments upon upper part of unruled sheet and explanatory notes on lower half. (5) Define (a) radiation, (b) absorption, and (c) conduction of heat. (6) Name some natural objects that are good (a) radiators, (b) absorbers, and (c) conductors of heat.

2. Burn small quantity of gasoline upon water in test tube and hold wire above flame. (2) Test temperature of water beneath flame and wire above. (3) Explain difference in temperature of water and wire. (4) Make, letter, and explain drawing. (5) Define (a) reflection and (b) absorption of heat.

3. Pass metal ball through ring. (2) Heat ball and try to repeat. (3) Cool ball or heat ring and repeat. (4) Observe effect of heat and of cold upon size of solids. (5) Make, letter, and explain drawings as in No. 1.

4. Place test tube with water over flame. (2) Note change in volume of water. (3) Make two drawings upon upper part of paper to illustrate effect of heat upon volume of liquids. (4) What causes water to boil over?

5. Hold corked test tube over flame. (2) Observe results. (3) Make, letter, and explain two drawings. (4) What effect has heat upon volume of gases? (5) What causes gas tanks or boilers to explode?

6. Imagine small quantity of ice or sulphur in dish over flame. (2) Note changes in form. (3) What is it that changes (a) solids to liquids and (b) liquids to gases? (4) Name three forms of matter. (5) Make and explain two drawings.

7. Place side of bent tube, convection apparatus, containing liquid over flame. (2) Indicate direction of circulation by means of colored arrows in drawing half page size. (3) Define convection. (4) What causes water to circulate? (5) What causes ocean currents?

8. Place flame in left tube of convection apparatus. (2) Hold lighted torch above each tube. (3) Make drawing on upper part of page. (4) Indicate direction of air currents by colored arrows. (5) What causes air to circulate? (6) Read Moore, page 51.

II. WRITTEN REVIEW.

1. Define matter. (2) Discuss structure of matter. (3) Read *Realm of Nature*, page 27. (4) Give examples of each form of matter. (5) State effect of intense cold upon (a) water and (b) air. (6) Read Moore, page 26.

2. Define heat. (2) Discuss four original sources of heat. (3) State which source is most important to earth. (4) State effect of intense heat upon (a) solids and (b) liquids.

3. Explain why volume of warm air or water should weigh less than same volume of cold air or water. (2) State why smoke rises in flue.

4. Explain why cold water flows toward the fire box and warm water rises in water tank. (2) Give location of hottest and coldest belts upon earth. (3) Which way does air and water of globe flow in respect to heat and cold belts? (4) See maps of winds and ocean currents in reference books.

5. Which is better reflector, land or water surface? (2) Explain why continents are warmer in summer than oceans.

6. Explain in separate paragraphs and give examples in nature of (a) radiation, (b) absorption, (c) reflection, (d) conduction, (e) convection. (2) State what causes liquids and gases to circulate. (3) State by what means large buildings and ocean steamers are usually ventilated.

III. REFERENCE BOOKS.

1. Realm of Nature, Chapters I, II, III.
2. Story of Atmosphere, Chapter IV.
3. Moore's Descriptive Meteorology, Chapters V, VII.
4. Books on Physics.
5. Davis's Elementary Meteorology, Chapter III.
6. Waldo's Elementary Meteorology, Chapter II.
7. Salisbury's Physiography, Chapter XIII.

EXERCISE VII. THERMOMETERS.

I. DIRECTIONS, ETC.

1. Read what is said in references concerning thermometers and thermographs. (2) Record upon cross-ruled paper daily for month, temperature of room by means of (a) Fahrenheit and (b) Centigrade thermometers.

2. Keep over flame thermometer tube containing small quantity of air and mercury, until mercury fills tube. (2) Seal tube and allow mercury to cool. (3) What is space above mercury called? (4) Make upon upper part of page three drawings of experiments about 4 inches long. (5) Explain drawings separately upon lower part of page.

3. Keep lower part of tube submerged in cracked ice or snow until contraction of mercury ceases. (2) Mark point of minimum contraction of mercury. (3) What is point called? (4) Make drawing of experiment and explain beneath.

4. Suspend thermometer tube in long-neck flask containing boiling water. (2) Cork neck of flask. (3) Mark maximum expansion of mercury in tube. (4) What is point called? (5) Make drawing of experiment and explain beneath.

5. Draw two thermometers, Fahrenheit and Centigrade, 25 centimeters long, upon metric ruled or blank paper. (2) Make drawings in form of rectangle. (3) Make upper and lower lines of diagrams indicate boiling and freezing points of water, and 18 centimeters apart. (4) Grade each instrument by dividing space between boiling and freezing points into required number of parts. (5) See that readings of thermometers correspond. (6) Notice that thermometers register actual temperature of room.

6. Draw from inspection maximum and minimum thermometers. (2) Explain drawings. (3) See that readings in drawings are same as readings upon thermometers. (4) How does steel index work? (5) Mention use of constriction. (6) Read Davis, page 60.

II. WRITTEN REVIEW.

1. Describe in separate paragraphs kinds of material necessary for construction of thermometers. (2) Give reasons for use of each material. (3) State how each thermometer tube is graded.

2. Describe (a) how vacuum is formed in thermometer tube and mention its use; (b) how freezing point is determined; (c) how boiling point is determined; (d) how one degree upon each thermometer tube is determined.

3. Deduce formulas for transposing terms of one thermometer into terms of another. (2) Test formulas by transposing daily readings of one thermometer into readings of another thermometer. (3) Use daily record No. 1.

4. Name some advantages or uses of maximum and minimum thermometers. (2) Give short description of construction and use of each instrument. (3) What kind of liquid is used in minimum thermometer? Why?

5. What principle is used in construction of thermometers? (2) For what does zero stand upon each instrument? (3) What is meant by absolute zero? (4) What is cold? (5) See paper thermometer on wall for low readings and absolute zero; also Moore, pages 54-55.

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Appendix G.
2. Waldo's Elementary Meteorology, pages 31-33.
3. Davis's Elementary Meteorology, Chapter V.
4. Moore's Descriptive Meteorology, Chapter VI.
5. Realm of Nature, pages 341-342.
6. Story of Atmosphere, page 89.
7. Dryer's Physical Geography, Appendix.
8. Salisbury's Physiography, Chapter XIII.

EXERCISE VIII. DAILY CHANGE IN TEMPERATURE.

I. DIRECTIONS, ETC.

1. Draw thermograph, full-page size, from inspection of instrument. (2) Letter principal parts of drawing. (3) Mention use of each part. (4) Make cylinder, full size. (5) Indicate direction of movement of cylinder by means of arrows. (6) State what part of thermograph expands and contracts. (7) What turns cylinder? (8) See thermograph and read Davis, page 58.

2. Notice how sheet upon cylinder is lined and numbered. (2) State what lines and spaces between lines represent. (3) What does line made by pen upon sheet represent? (4) What is sheet and pen line called?

3. Draw from thermal sheets upon sheet of metric paper two thermal lines in red. (2) Make first line to represent changes in temperature for two consecutive clear days. (3) Make second line to represent two consecutive cloudy days. (4) See thermal sheets for clear and cloudy weather. (5) Begin lines at midnight. (6) Allow one centimeter for two hours. (7) One centimeter for 5°. (8) Date lines as per thermal sheets. (9) Fold sheet lengthwise. (10) Use upper and lower halves separately.

4. State when (a) minimum and (b) maximum temperature of each day occurs. (2) Find difference in daily extremes of temperature. (3) What is difference called? (4) Compare range of temperature during clear and cloudy weather. (5) Read Dryer, page 28, or Tarr, page 241.

5. Insert table, page 28, Waldo. (2) Illustrate table by drawing upper part of figure 392 in Tarr full width of page. (3) Make lines represent sun's rays at angles given in table, and 1 centimeter in width. (4) Place table and drawing on same page. (5) State three facts table is designed to show. (6) See diagrams upon wall.

6. Select from summer "weather map," and give date, (a) 10 interior cities and (b) 10 seaport cities. (2) Find their average (a) maximum, (b) minimum, and (c) range of temperature. (3) Make averages in red. (4) Compare averages in temperature of interior cities with those of seaport cities. (5) Give reasons for difference observed. (6) See form for tabulation on wall.

II. WRITTEN REVIEW.

1. State what part of thermograph is substituted for mercury in thermometer. (2) State how change of temperature is communicated to pen. (3) Name some advantages of thermographs. (4) State how thermal sheet is ruled and numbered. (5) How does thermal line show changes in temperature?

2. Express in words ordinary change in temperature for one clear day. (2) Explain fully (a) why maximum temperature occurs about middle of afternoon, and (b) minimum about sunrise. (3) State what you observe concerning (a) maximum, (b) minimum, and (c) range of temperature during clear and cloudy weather. (4) Give reasons for observations.

3. What kind of temperature should be expected (a) upon clear nights in winter, (b) upon clear days in summer? (2) How would low temperature affect water pipes and plants? (3) State what you observe, and give reasons in each case.

4. Compare averages of interior cities with averages of seaport cities. (2) State effect of water bodies and dry places upon (a) maximum, (b) minimum, and (c) range of temperature. (3) Account for differences of temperature between eastern and western Washington. (4) Read Dryer, page 300.

5. State relation between (a) angle of sun and amount of heat received, (b) angle of sun and amount of surface covered, (c) units of atmosphere and amount of heat. (2) See table and illustration in No. 5.

III. REFERENCE BOOKS.

1. Waldo's Elementary Meteorology, Chapter II.
2. Tarr's Physical Geography, Chapter XII.
3. Dryer's Physical Geography, Chapter XXV.
4. Moore's Descriptive Meteorology, Chapters VI, VII.
5. Story of Atmosphere, Chapter IV.
6. Story of Atmosphere, figures 4, 5.
7. Davis's Elementary Meteorology, Chapter V.
8. Salisbury's Physiography, Chapter XIII.

EXERCISE IX. SEASONAL CHANGE IN TEMPERATURE.

I. DIRECTIONS, ETC.

1. Draw in red, upon chart of world, isotherms for July. (2) Number lines as per chart. (3) Note how thermal numbers increase or decrease in respect to equator. (4) Locate definitely and color places of greatest heat. (5) See thermal charts for July and January in reference books, also charts 2 and 3, Moore.

2. Note whether or not isotherms bend toward or away from equator in crossing continents. (2) Do same in respect to oceans. (3) State what bends observed indicate regarding comparative temperature over land and sea in July.

3. Compare positions of isotherms of 70° north and south in respect to equator. (2) Note comparative latitude of same thermal line near eastern and western coasts of continents. (3) Determine whether or not temperature is equal in same latitudes north and south, and east and west.

4. Treat January chart in same manner as July chart, and repeat Nos. 1, 2, 3.

5. Read Tarr, pages 276 to 279, prepare summary with examples to illustrate what is said concerning influence of (a) latitude, (b) altitude, (c) oceans, (d) deserts, and (e) north and south slopes upon temperature. (2) Read Moore, page 115, or Waldo, page 58.

6. Determine, by use of tellurian, latitude of vertical sun on June 21 and December 21. (2) Illustrate same by drawing together in red and black, figures 549 and 551, Tarr. (3) Compare positions of maximum temperature for July and January. (4) Prepare reasons for changes in positions.

II. WRITTEN REVIEW.

1. State how temperature increases or decreases in respect to latitude. (2) Give reasons. (3) See No. 5, Exercise VIII. (4) Name countries which are hottest in July. (5) Give at least two reasons. (6) Do same in respect to January.
2. State which way thermal lines bend in crossing oceans, in (a) summer, and (b) winter. (2) Do same in respect to continents. (3) Give reasons in each case. (4) Give reasons why thermal lines do not coincide with parallel lines.
3. Compare isotherms south with same isotherms north of equator in respect to regularity. (2) Do same in respect to land and water surfaces. (3) Give reasons for observations.
4. State in separate paragraphs and give examples of influence of (a) altitude, (b) latitude, (c) oceans, (d) winds, (e) ocean currents, (f) clouds, (g) desert, and (h) direction of mountain slopes upon temperature. (2) Give reasons why all places in same latitude do not have same temperature. (3) Define (a) isothermal line, (b) thermal equator. (4) Locate thermal equator and state why so located.
5. State upon what lines sun is vertical June 21 and December 21. (2) Explain why (a) maximum temperature occurs in July and (b) minimum in January. (3) State what causes thermal lines and belts to change positions.
6. Name principal places in North America through which July isotherms of 60° passes. (2) Do same with January line of 60°. (3) Give reasons for difference in position and regularity of line.

III. REFERENCE BOOKS.

1. Waldo's Elementary Meteorology, Chapter II.
2. Tarr's Physical Geography, Chapter IV.
3. Story of Atmosphere, Chapter IV.
4. Moore's Descriptive Meteorology, Chapter VII.
5. Realm of Nature, Chapter VII.
6. Davis's Elementary Meteorology, Chapter V.
7. Dryer's Physical Geography, Chapter XV.
8. Salisbury's Physiography, Chapter XIII.

EXERCISE X. BAROMETERS.

I. DIRECTIONS, ETC.

1. Record daily for month, upon cross-ruled paper, atmospheric pressure as indicated upon barometer or barograph. (2) Date sheet. (3) Record kind of weather as "Fair," "Cloudy," "Rainy," etc. (4) Continue to record temperatures. (5) Read Ward's Exercises in Elementary Meteorology, Chapter I.
2. Read references concerning barometers and barographs. (2) State what demonstrations with (a) air pump, (b) inverted glass of water, and (c) balances are designed to show. (3) Read Davis, page 82, Moore, pages 127-182, or Waldo, page 75.
3. Fill glass tube about 3 feet long with mercury. (2) Invert filled tube in bowl containing mercury. (3) Observe that end of tube does not rest on bottom of bowl. (4) Notice that mercury has fallen in tube. (5) What is empty space above mercury called? (6) How is it formed? (7) What keeps mercury up in tube?
4. Draw upon metric or unruled paper-bent tube; tube and bowl and stand together. (2) Make tubes about 24 centimeters long and 1 centimeter wide. (3) Make bowl and bend in tube about 4 centimeters across. (4) See apparatus, drawings upon wall, and illustrations in reference books.

5. Grade tubes from 25 to 35 inches by allowing two and one-half centimeters for each inch. (2) See that mercury in bowl and tube is on same level. (3) Measure height of mercury in tubes from surface of mercury in bowl and tube. (4) Compare measurements with actual readings upon standard barometers.
- 6. Insert table, page 75, Waldo. (2) State what table is designed to show. (3) Determine which weighs more per cubic foot, (a) dry air or water vapor, (b) warm or cold air. (4) How does barometer stand during rainy weather? Why? (5) Read Story of Atmosphere, page 27.

II. WRITTEN REVIEW.

1. How high is atmosphere supposed to extend? (2) Read Moore, page 8, or Davis, page 13. (3) What is weight or pressure of atmosphere on square inch; on square foot? (4) In which direction is pressure exerted? (5) Refer to experiments.
2. What effect has altitude upon pressure? Why? (2) Give approximate pressure of atmosphere upon summit of Mount Tacoma (14,500 feet) when barometer registers 30 inches at sea level. (3) State effect of water vapor in air upon barometric pressure. (4) Read Moore, page 200, or Davis, page 143.
3. Compare weight of mercury with that of water. (2) How high will water rise in vacuum? Why? (3) How high will mercury rise in vacuum? Why? (4) What causes water to rise in ordinary pumps or tubes? (5) Explain what is meant by suction.
4. State briefly history of barometer. (2) Read Story of Atmosphere, page 25. (3) Describe how vacuum is formed in barometer tube. (4) Mention use of vacuum. (5) Describe how simple barometer is constructed and graded.
5. Compare working of balances with working of barometer. (2) State principle used in construction of barometers. (3) Give reasons for use of long tube. (4) Why is mercury used in barometers?
6. Name practical uses of barometers. (2) Express in inches what constitute (a) high, (b) low, and (c) normal barometers at sea level. (3) State kind of weather indicated by "Low" and by "High" barometers. (4) Give reasons in each case.

III. REFERENCE BOOKS.

1. Waldo's Elementary Meteorology, Chapter III.
2. Davis's Elementary Meteorology, Chapter VI.
3. Story of Atmosphere, Chapter III.
4. Moore's Descriptive Meteorology, Chapter IX.
5. Tarr's Physical Geography, pages 420-422.
6. Dryer's Physical Geography, Chapter XXVI.
7. Marvin's "Barometers, etc."
8. Salisbury's Physiography, Chapter XV.

EXERCISE XI. DAILY CHANGE IN PRESSURE.

I. DIRECTIONS, ETC.

1. Continue to record daily barometric pressure. (2) Record daily whether or not barographic line is "rising," "falling," or "even." (3) Note kind of line associated with unusually "good" or "bad" weather, also with severe "storms" or "violent" winds. (4) Observe barographs daily.
2. Read Davis, page 84, and Moore, page 131. (2) Draw barograph full page size from inspection of instrument. (3) Letter principal parts of drawings. (4) State use of each part. (5) Make cylinder full size. (6) What turns cylinder?

3. Note how sheet upon cylinder is ruled, lettered, and numbered. (2) State what lines and spaces between lines represent. (3) What does line made by pen upon sheet represent? (4) What is sheet and pen line called?

4. Draw from barographic sheets upon metric ruled paper two barographic lines in red. (2) Make first to represent "clear" or "good" weather. (3) Make second to represent "rainy" or "bad" weather. (4) See barographic sheets for "good" and "bad" weather. (5) Begin lines at midnight. (6) Allow 2.5 centimeters per inch. (7) Allow 1 centimeter for six hours. (8) Date lines as per sheets. (9) Fold metric sheets lengthwise. (10) Use upper and lower halves separately.

5. Determine from inspection of lines, interval of time usually between one maximum and another. (2) Compare two barographic lines. (3) State which one has higher pressure. (4) Apply and remove pressure by breathing through attached tube on demonstration barometer. (5) What does demonstration show?

II. WRITTEN REVIEW.

1. State what part of barograph is substituted for mercury in standard barometer. (2) Name two parts of barograph that correspond to two parts of balances. (3) Which way does cylinder turn in respect to pen?

2. Explain how changes in pressure are communicated to pen. (2) State how barographic line indicates change in pressure. (3) What kind of line indicates (a) "good," (b) "bad," (c) stormy weather, or (d) violent winds?

3. State from inspection of barometric line approximate interval of time usually between maximum and minimum pressures. (2) State how often weather conditions usually change. (3) State what kind of weather is indicated (a) by "rising" barographic line, (b) by "falling" line, (c) by "even" or straight line, (d) by "very steep" or V-shaped line. (4) Read Dryer, page 324.

4. Mention advantages of barographs. (2) Name some practical uses of barographs and barometers to (a) sailors, (b) farmers, (c) mountaineers, (d) builders, and (e) aviators. (3) Explain how altitude is determined by barometers.

5. State effect of atmospheric pressure upon breathing. (2) How does water vapor in air affect barographs? (3) State how barographs indicate increase or decrease in air pressure and change of weather. (4) Give brief description of aneroid barometers. (5) See instrument and read Moore, page 130.

III. REFERENCE BOOKS.

1. Waldo's Elementary Meteorology, Chapter III.
2. Davis's Elementary Meteorology, Chapter VI.
3. Story of Atmosphere, Chapter III.
4. Moore's Descriptive Meteorology, pages 127-138.
5. Tarr's Physical Geography, pages 420-422.
6. Dryer's Physical Geography, Chapter XXVI.
7. Marvin's "Barometers, etc."
8. Salisbury's Physiography, Chapter XVI.

EXERCISE XII. SEASONAL CHANGE IN PRESSURE.

I. DIRECTIONS, ETC.

1. Draw colored isobaric chart of world for July. (2) Number isobaric lines as per chart. (3) Print upon chart word "High" or "Low" in proper areas, north and south. (4) See isobaric charts in reference books.

2. Locate places of maximum and minimum pressures in middle latitudes, north and south. (2) Notice whether high pressures are mostly over land or

sea. (3) Notice in about what latitude high-pressure areas are located. (4) See charts, and Waldo, page 96, or Moore, page 134.

3. Draw isobaric chart of world for January, and repeat as in Nos. 1 and 2.

4. Compare latitude of July high pressure north with January high pressure. (2) Compare their positions in respect to land and water surfaces. (3) Prepare reasons for change observed. (4) What effect has heat upon pressure? (5) Compare extent of high pressure in winter with that in summer.

5. Indicate upon charts wind directions by means of arrows. (2) Observe whether or not surface air moves toward or from high-pressure belts. (3) Note which way winds blow in respect to continents (a) in summer, and (b) in winter. (4) See *Realm of Nature*, pages 116 and 124, or Waldo, pages 91 and 93.

6. Determine which weighs more per unit volume, warm air or cold air. (2) Note positions of "High" and "Low" pressures in summer and in winter in respect to land and water. (3) Read *Story of Atmosphere*, page 27, and prepare summary.

II. WRITTEN REVIEW.

1. State in what ways atmosphere pressure is represented upon charts. (2) What are pressure lines called? (3) In what terms are such lines numbered? (4) What line separates "High" and "Low" pressure areas? (5) What are areas without line called? (6) Read Moore, page 135.

2. Compare extent of surface covered by high pressure in summer with that in winter. (2) Compare temperature over land with pressure over land (a) during winter and (b) during summer. (3) Do same in respect to oceans. (4) State relation of heat and pressure. (5) State why pressure is low in equatorial belt.

3. What effect has heat upon pressure? (2) Explain why pressure belts and line change positions with change of seasons. (3) See barometric charts for July and January. (4) Give example to illustrate answer.

4. Compare summer pressure with winter pressure over continents. (2) How is wind direction indicated upon maps? (3) State which way winds blow in respect to land and water masses in (a) summer and (b) winter. (4) State which way winds blow in respect to high and low pressure areas. (5) Which way streams flow in respect to high and low places.

5. How does warm air compare in weight to cold air? (2) Explain why air rises over hot places and settles over cold places. (3) Why does wind blow toward land in summer and away from it in winter? (4) Why should pressure be greater upon land in winter than in summer?

III. REFERENCE BOOKS.

1. Davis's *Elementary Meteorology*, Chapters II-VI.
2. Waldo's *Elementary Meteorology*, Chapter III.
3. *Realm of Nature*, pages 116-124.
4. Moore's *Descriptive Meteorology*, pages 127-138.
5. *Story of Atmosphere*, Chapter III.
6. Dryer's *Physical Geography*, Chapter XXVI.
7. Salisbury's *Physiography*, Chapter XV.
8. Bartholomew's *Physical Atlas*.

EXERCISE XIII. PRESSURE AND WINDS.

I. DIRECTIONS, ETC.

1. Determine average latitude, north and south, of high and low pressure belts for year. (2) See page 96, Waldo, or Moore, page 134. (3) Draw upon chart of world in latitudes given, colored belts, half centimeter wide, to represent

pressures. (4) Place in belts (a) words "High" or "Low" in proper places; also (b) pressures in figures.

2. Indicate by arrows directions of winds in each belt. (2) Note relation between wind directions and pressure belts. (3) Read Tarr, page 255. (4) Rotate black globe from west to east. (5) Note effect of rotation upon wind direction in (a) equatorial, and (b) temperate belts. (6) Read Dryer, pages 306-311, or Moore, page 141.

3. Print upon chart in proper belts, (a) northeast trades, (b) southeast trades, (c) westerlies, and (d) circumpolar. (2) Note wind direction and latitude of each wind belt. (3) Do wind belts change positions? Why? (4) See Davis, page 121, or Moore, page 140.

4. Draw lengthwise, upon lower half of metric ruled paper, cross-section of chart No. 1. (2) Allow 1 centimeter for each 10 degrees of latitude. (3) Allow 2 millimeters for each tenth inch of pressure. (4) Insert pressures in figures in proper latitudes. (5) Indicate wind directions and slopes by lines and arrows. (6) Insert names of winds in proper places. (7) See Davis, page 89, or Waldo, page 97.

5. Describe, by means of cross-section, circulation of atmosphere from equator to poles and return. (2) Give (a) name, (b) direction, (c) latitude and altitude of winds in each belt. (3) State what makes air rise near equator. (4) What makes air settle near 30 and 35 degrees, north and south.

6. Determine what is meant by barometric gradient. (2) How is value of gradient determined? (3) Read Waldo, page 100, Salisbury, page 396, or Moore, page 135. (4) Show meaning by use of cross-section. (5) How does gradient effect velocity of winds? (6) What kind of wind does V-shaped or very steep barographic line represent?

II. WRITTEN REVIEW.

1. Explain what causes winds. (2) Explain effect of earth's rotation upon wind direction in (a) equatorial and (b) temperate belts. (3) Mention wind directions in each belt, if earth did not rotate. (4) What causes low pressure near equator? (5) What causes high pressure near middle latitudes? (6) What causes low pressure near latitudes 65°, north and south?

2. Give latitudes, (a) directions and (b) character, of following winds and wind belts in separate paragraphs: (a) Trades, (b) antitrades, (c) prevailing westerlies, (d) horse latitudes, (e) circumpolar winds, (f) return westerlies, and (g) belt of calms. (2) Read Davis, page 117, Tarr, pages 258 to 262, or Moore, page 178.

3. State in separate paragraphs effect of winds upon (a) ocean currents, (b) ocean commerce, (c) surface of earth, (d) distribution of moisture, (e) distribution of plant life, (f) equalization of temperature, (g) and general health.

4. Determine by use of cross-section value of gradients for trades and westerlies north. (2) How is velocity of winds indicated upon barometric sheets? (3) Mention some practical uses of winds.

III. REFERENCE BOOKS.

1. Waldo's *Elementary Meteorology*, Chapters III-VIII.
2. *Realm of Nature*, Chapter VIII.
3. Ferrel's "Winds."
4. Moore's *Descriptive Meteorology*, Chapters IX, X.
5. Davis's *Elementary Meteorology*, Chapter VII.
6. Dryer's *Physical Geography*, Chapter XXVI.
7. *Story of Atmosphere*, Chapter V.
8. Salisbury's *Physiography*, Chapters XV, XVI.

EXERCISE XIV. WIND DIRECTIONS AND RAINFALL.

I. DIRECTIONS, ETC.

1. Trace in ink upon chart of world or each continent (a) shore lines, (b) rivers, (c) lakes, and (d) mountains. (2) Indicate in colors and figures upon each continent rainfall for summer. (3) Insert names and indicate wind directions in each belt. (4) Print word "Dry" in red upon places dry for one season and word "Desert" on places dry for years. (5) Insert upon chart words "High" or "Low" in proper places upon oceans, north and south. (6) See charts for wind directions and rainfall.

2. Note general directions of (a) mountains and (b) river systems upon each continent. (2) Determine between what parallels north and south (a) trade winds and (b) prevailing westerlies are situated. (3) State whether or not winds blow toward or away from continents upon eastern or western coasts in (a) trade and (b) westerly belts. (4) Observe whether or not deserts are situated upon "windward" or "leeward" side of mountain ranges. (5) Observe same in respect to rain belts. (6) Note whether or not river systems generally flow with or against prevailing wind directions. (7) Read Dryer, pages 327 to 334; Tarr, pages 22 to 30; or Moore, pages 265 to 266.

3. Draw chart of world or continents for winter and repeat data in Nos. 1 and 2.

4. Draw upon charts of United States or Washington (a) wind directions and (b) rainfall in colors and inches for July and January. (2) See wind charts for summer, Dryer, pages 305 to 330. (3) Note difference in wind directions and rainfall for July and January. (4) State causes of changes. (5) See Government rain charts for summer and winter.

5. Record wind directions daily for month. (2) Use initial letters, as N., S., NE., SW., etc. (3) Use mariner's compass in determining directions. (4) Observe cloud or smoke drift, also wind vane upon roof. (5) Read (a) Salisbury, Chapter IX, (b) Realm of Nature, page 60, or (c) Tarr, Appendix F.

II. WRITTEN REVIEW.

1. State definitely where maximum rainfall in North America occurs in winter and in summer. (2) Explain why maximum rainfall occurs at that season and place. (3) In what wind belt is maximum rainfall in winter and in summer?

2. Repeat No. 1 in separate paragraph in respect to each continent.

3. Give directions of river systems on each continent in respect to (a) wind direction and (b) mountain systems. (2) Give reasons why Columbia flows west, Amazon east, Mississippi south. (3) Why should Amazon be larger than Columbia? (4) What winds supply La Plata and Orinoco with water? (5) Read Salisbury, pages 396 to 491.

4. State definitely where and in what wind belt each great desert is situated. (2) Give reason why each desert is so located. (3) During what seasons and by what winds is Nile supplied with water? (4) Read Davis, pages 296 to 310.

5. Locate upon each continent rain and rainless belts, if earth were to rotate from east to west. (2) Describe condition (a) in South America if Andes were upon eastern side of continent, (b) in Australia if mountains were upon western side, and (c) in Washington if there were no Cascade Mountains. (3) Describe wind vane upon roof. (4) Which way does arrow point in respect to wind directions? (5) Read Moore, pages 172 to 176.

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter XIV.
2. Dryer's Physical Geography, Chapter XXVIII.
3. Waldo's Physical Geography, Chapters IV-XII.
4. Salisbury's Physiography, Chapter XVI.
5. Davis's Elementary Meteorology, Chapter XII.
6. Realm of Nature, Chapter IX.
7. Moore's Descriptive Meteorology, page 265.
8. Physical Atlas and Maps.

EXERCISE XV. HIGH AND LOW PRESSURE STORMS.

I. DIRECTIONS, ETC.

1. Read what is said in references concerning cyclones and anticyclones. (2) Continue to record wind directions. (3) Insert in two columns names and velocities of wind in miles. (4) Read Davis, page 94, or Moore, pages 172-177. (5) Determine from inspection of tables what is meant by wind pressure. (6) Determine relation between wind velocity and pressure. (7) Read references relating to anemometers and prepare summary.

2. Insert enlarged half page, figures 29 and 30, Realm of Nature. (2) Print in red words "High" or "Low" in center of figures. (3) Divide figures into quarters by light pencil lines, north and south, east and west. (4) Indicate position of each quarter by inserting in red proper initial, as SE, SW., NW., or NE.

3. Note (a) wind directions and (b) condition of sky in middle of each quarter of "Low." (2) Note whether or not winds move in or out of low pressure directly or spirally. (3) Observe whether movement is from left or right or otherwise in southern half of "Low." (4) See figures 53 or 58, Davis. (5) Repeat same for "Highs."

4. Insert enlarged upon upper part of paper, figure 292, Dryer, or figure 73, Waldo. (2) Print in centers of whirls words "High" or "Low." (3) Draw pencil line through center of figure and note directions N. and S. (4) Note from figure how winds flow out of high pressure into low pressure in southern halves.

5. Insert upon lower part of page cross and vertical sections of high and low pressure areas, figures 412 and 417, Tarr. (2) Print word "Sky" above each figure and words "High" or "Low" immediately beneath. (3) Note wind directions in center of each pressure. (4) Note relation of barometric line to high and low pressure.

II. WRITTEN REVIEW.

1. State differences between "Cyclones" and "Anticyclones," or "Low" and "High" pressure storms; use diagrams. (2) Give directions of spiral whirl in southern half and in center of cyclones. (3) Do same with anticyclones. (4) State effect of (a) rising and (b) falling air upon barometer.

2. In what direction do low-pressure storms move in (a) Equatorial and (b) Temperate Zones? (2) Read Dryer, page 318. (3) What part of storm is front? (4) Standing with back to wind, where is center of low pressure, on right or left?

3. State how coming of low-pressure storms are indicated by (a) barograph, (b) thermograph, (c) wind direction, (d) condition of sky. (2) Do likewise

with high-pressure storms. (3) What part of low-pressure storms are most dangerous? (4) What instrument is most useful in indicating coming storms?

4. State what wind velocity is considered dangerous to buildings or shipping. (2) State pressure per square foot at velocity mentioned. See tables, Davis or Moore. (3) What is relation between wind velocity and pressure? (4) Explain how wind velocity is measured. (5) How are winds classified? (6) Read Moore, Chapter X.

5. State kind of pressure over north Pacific in (a) summer and (b) winter. (2) Give direction of winds upon northwest coast of North America in summer and in winter. (3) Mention effect of wind directions on rainfall and give examples.

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter XIII.
2. Dryer's Physical Geography, Chapter XXVII.
3. Realm of Nature, Chapter IX.
4. Moore's Descriptive Meteorology, Chapters IX-XIII.
5. Story of Atmosphere, Chapters IX-XIII.
6. Waldo's Elementary Meteorology, Chapters VIII, IX.
7. Davis's Elementary Meteorology, Chapter X.
8. Salisbury's Physiography, Chapter XVII.

EXERCISE XVI. WEATHER MAPS.

I. DIRECTIONS, ETC.

1. Draw from selected weather map, upon chart of United States, (a) "Low" over Mississippi Valley, (b) "High" over eastern and western coasts. (2) Draw isotherms in red and isobars in black. (3) Date chart. (4) Enlarge half inch, characters in explanatory notes upon weather maps. (5) Place enlarged character upon margins of charts.

2. Draw pencil lines through center of "Low" in No. 1 from east to west, north to south. (2) Note from inspection of map (a) wind directions, (b) temperature, and (c) condition of sky respecting clouds, rain, snow, etc., in middle of each quarter, beginning with southeast. (3) For sample chart see No. 19, Moore, or figure 404, Salisbury.

3. Draw as indicated in Nos. 1 and 2 "High" over Mississippi Valley, with "Lows" over eastern and western coasts. (2) Read Realm of Nature, pages 142 to 152. (3) For sample chart see Salisbury, figure 405, or Moore, chart No. 20.

4. Compare (a) barometric lines with contour lines, and (b) barometric gradient contour slope. (2) State similarity or difference. (3) Note from inspection of map comparative wind velocity in rear and front of storm. (4) Determine which way storms move through United States in temperate belt. (5) Waldo, page 223, or Moore, charts Nos. 32 and 33.

5. Draw in proper colors set of "Storm signals," (a) size, 4 centimeters square, black center, one-third width; (b) pennants, 8.5 centimeters long and 4 centimeters wide. (2) Draw in proper colors set of "Weather signals," (a) size, 4 centimeters square, (b) label each signal, and (c) state in which quarter of "storm" each signal should appear. (3) See United States signal cards or flags.

II. WRITTEN REVIEW.

1. Give wind direction and weather conditions in (a) eastern, (b) western, and (c) central part of United States as per chart No. 1. (2) State conditions

of (a) barometer, (b) thermometer, (c) sky, and (d) wind directions before coming of low pressure storm from west. (3) State direction of forward movement.

2. Give direction and weather conditions in (a) eastern, (b) western, and (c) central part of United States as per chart No. 2. (2) State conditions of (a) barometer, (b) thermometer, (c) sky, and (d) wind directions before coming of anticyclone or high-pressure storm from the west.

3. Determine barometric gradient in (a) front and (b) rear of "low" in chart No. 1. (2) State which gradient is usually steeper, "front" or "rear." (3) Mention relation between gradient and wind velocity. (4) Read Salisbury, page 396. (5) How does distance between isobars indicate velocity of wind? (6) Read Waldo, page 100, *Realm of Nature*, 116.

4. State in what ways (a) wind directions, (b) wind velocity, (c) barometric gradients are shown upon weather maps. (2) State how (a) temperature, (b) pressure, (c) condition of sky are indicated upon weather map. (3) Examine charts.

5. Describe proper "storm signal" to be used in each quarter of storm. (2) What kind of signal is used in case of hurricane? (3) How are very strong winds indicated upon weather map? (4) Upon barographic sheet? (5) Name proper storm signals to be used in case of low-pressure storm coming from west.

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter XIII.
2. Dryer's Physical Geography, Chapter XXVII.
3. *Realm of Nature*, Chapter IX.
4. Salisbury's Physiography, Chapter XVII.
5. *Story of Atmosphere*, Chapters I, X, XII.
6. Waldo's *Elementary Meteorology*, Chapters VIII, IX.
7. Davis's *Elementary Meteorology*, Chapter X.
8. Moore's *Descriptive Meteorology*, Chapter XIII.

EXERCISE XVII. SPECIAL WINDS AND STORMS.

I. DIRECTIONS, ETC.

1. Prepare explanation for (a) land breezes and (b) sea breezes. (2) Note (a) causes, (b) time of occurrences, and (c) direction of winds. (3) Read *Realm of Nature*, pages 122 to 126, and enlarge upon upper and lower halves of page, figures 25 and 26. (4) Read Davis, pages 134, 313; Waldo, page 262, or Moore, page 182, and prepare summary.

2. Draw upon upper and lower halves of page two maps of India, one for summer and one for winter. (2) Indicate upon maps (a) latitude, (b) mountains, (c) rivers, (d) wind directions, (e) rainfall in colors, (f) pressure lines, and (g) words "High" and "Low" in proper places. (3) Read Tarr, pages 257 and 284; Davis, page 123, or Moore, page 180. (4) Note (a) wind direction and (b) rainfall during (a) summer, (b) winter.

3. Determine what is meant by mountain and valley winds. (2) Prepare explanation for (a) causes and (b) time and place of occurrence, and (c) character of (a) Foehn, (b) Chinook, (c) Sirocco, and (d) Mistral. (3) Read Davis, page 137; Waldo, page 262, or Moore, page 184.

4. Read Waldo, page 287, or Moore, page 223, and prepare summary of what is said concerning cold and hot waves. (2) Read Moore, pages 185 to 188, and inspect charts Nos. 24, 25.

5. Insert upon upper and lower parts of page vertical and cross sections of hurricane, figures 426 and 428, Tarr. (2) Draw through center of figure two straight lines at right angles. (3) Note direction of spiral whirl in upper, center, and lower parts of figure 425. (4) Note direction of forward movement of storm. (5) What is meant by front and rear of storm? (6) Notice how storm is represented upon weather map in figure 427, also by barographic line, figure 297, Dryer.

II. WRITTEN REVIEW.

1. State comparative temperature over land and water during day and night, summer and winter. (2) What effect has heat upon atmospheric pressure? (3) What causes land and sea breezes? (4) Mention some places where land and sea breezes are strong. (5) State about what time of day each wind occurs.

2. In what wind belt is India? (2) Why is India not desert like Arabia? (3) Explain what causes wind to blow toward and away from India periodically. (4) Account for periodical floods and droughts in India. (5) Describe in separate paragraphs (a) summer and (b) winter monsoon in India.

3. What causes mountain and valley wind? (2) Mention some effects of such winds upon temperature and life. (3) Describe Foehn or Chinook winds as to cause, time of occurrence, and character. (4) Read Davis, page 234, or Moore, page 186.

4. Give cause and character of some hot winds. (2) Do same in relation to cold winds. (3) State effect of such winds upon life. (4) Read Davis, pages 230-233.

5. Mention important features of hurricanes. (2) Explain why such storms are so destructive to buildings. (3) What places are considered safest during tornadoes? (4) When and where do hurricanes or typhoons occur frequently? (5) Describe ordinary (a) whirlwind, (b) hurricane, (c) typhoon, or (d) tornado. (6) Read Dryer, pages 318 to 323. (7) State how violent storms are indicated by (a) barograph, (b) thermograph, (c) wind directions, and (d) conditions of sky. (8) How are such storms indicated upon weather map? By storm signals?

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter XIII.
2. Dryer's Physical Geography, Chapter XXVII.
3. Realm of Nature, Chapter IX.
4. Salisbury's Physiography, Chapter XVI.
5. Davis's Elementary Meteorology, Chapter VII.
6. Waldo's Elementary Meteorology, Chapter X.
7. Story of Atmosphere, Chapter IX.
8. Moore's Descriptive Meteorology, Chapters X-XIII.

EXERCISE XVIII. ATMOSPHERIC MOISTURE.

I. DIRECTIONS, ETC.

1. Record upon properly ruled paper condition of sky daily by using symbols upon United States weather maps. (2) Record kinds of clouds by using abbreviations shown upon United States cloud charts. (3) Examine charts and maps. (4) Read what is said in references regarding atmospheric moisture. (5) Insert upon properly ruled paper table, page 280, Dryer. (6) Note relation between saturated air and temperature.

2. Note what is said regarding (a) relative and (b) absolute humidity. (2) Note also effect of increase or decrease of temperature upon relative humidity. (3) Observe relative weight of dry air and water vapor. (4) Note change in volume from water to water vapor. (5) Read *Realm of Nature*, pages 42, 102, 104.

3. Draw from observation of instrument or pages 401-402, *Dryer*, hygrometer. (2) Determine by use of hygrometer and table, page 408, *Dryer*, relative humidity of room daily. (3) Explain drawing by means of letters. (4) Observe readings of each thermometer. (5) Determine which is lower. (6) Prepare explanation for difference. (7) See Exercise VII for scale for thermometers.

4. Make drawing of experiment to illustrate (a) evaporation and (b) condensation of moisture. (2) Letter different parts of drawing for explanation. (3) Note effect (a) of heat upon evaporation and (b) of cold upon condensation. (4) Insert table, page 147, *Davis*, and prepare explanation.

5. Observe from experiment what it is that causes condensation. (2) Enumerate four processes of cooling as given in *Dryer*, page 282. (3) State clearly substance of each paragraph separately. (4) Read carefully Chapter XII, *Moore's Descriptive Meteorology*.

II. WRITTEN REVIEW.

1. Explain table in No. 1. (2) How much does water expand before it becomes water vapor? (3) What is cause of expansion? (4) Explain what is meant by saturated air. (5) Name five conditions favorable for evaporation. (6) Name five benefits arising from evaporation of moisture.

2. Define and give examples of (a) absolute humidity, (b) relative humidity, and (c) point of saturation. (2) State effects of (a) increase or (b) decrease of temperature upon humidity. (3) Give examples to illustrate meaning. (4) What is meant by "damp air"?

3. Describe in full hygrometer. (2) State how (a) relative humidity and (b) dew points are determined by hygrometer and table. (3) Explain why reading upon one thermometer is less than reading upon other thermometer. (4) State effect of evaporation upon temperature. (5) Explain why it is cooler after rains in summer. (6) Why are summers in western Washington cooler than summers in eastern Washington?

4. Explain experiment in No. 4. (2) Mention some favorable condition for condensation. (3) Substitute blades of grass for cold-jar experiment, and explain formation of dew. (4) Substitute cold dust particles for cold jar, and explain formation of fog and clouds. (5) Read *Moore*, pages 204, 205.

5. Mention four ways through which condensation is produced. (2) Explain formation of fogs off shore. (3) Explain formation of clouds about mountain tops. (4) Why do clouds accumulate with south winds and disperse with north winds?

III. REFERENCE BOOKS.

1. *Dryer's Physical Geography*, Chapter XXIII.
2. *Sigsbee's Cloud Forms*.
3. *Moore's Descriptive Meteorology*, Chapters VI, VII.
4. *Tarr's Physical Geography*, Chapter XII.
5. *Waldo's Elementary Meteorology*, Chapter V.
6. *Harrington's "Weather,"* Chapters X, XI.
7. *Salisbury's Physiography*, Chapter XIV.
8. *Davis's Elementary Meteorology*, Chapter VIII.

EXERCISE XIX. MOISTURE (Continued).**I. DIRECTIONS, ETC.**

1. Classify cloud forms. (2) See Government charts and read references to clouds. (3) Note form, height, etc., of each class. (4) Insert mean height in table, page 179, Davis, or page 111, Story of Atmosphere. (5) Note from table whether clouds are higher in summer or winter. (6) State reason for observation.

2. Prepare in separate paragraphs short explanations with examples to illustrate following ways of causing rain: (a) Thunder storms, (b) cyclones, (c) doldrums, (d) volcanoes, (e) mountains, (f) intermingling winds, (g) land and sea breezes, (h) southerly winds. (2) Read references to each topic, also rainfall.

3. Read Dryer, Chapter XXVIII. (2) Observe and prepare to explain cause and distribution of rainfall as represented upon summer and winter charts. (3) Insert four general laws governing distribution of rainfall as given on page 333, Dryer.

4. Reproduce from books or charts four snow crystals 2 inches in diameter. (2) Note number of sides to crystals. (3) Mention condition most favorable to formation of snow. (4) Read Waldo, page 159, or Realm of Nature, page 113.

5. Record daily (a) kinds of clouds observed, (b) weather conditions, and (c) wind directions. (2) Note daily relation between (a) kind of clouds, (b) kind of weather and direction of winds. (3) Notice conditions of barometer daily.

II. WRITTEN REVIEW.

1. Enumerate in separate paragraphs chief features of each primary class of clouds. (2) Mention kind of weather usually associated with each class. (3) Read Realm of Nature, page 111, or Waldo, page 129.

2. Note general direction of mountain systems and prevailing winds upon each continent. (2) Compare height of rain-bearing clouds with height of mountains. (3) Locate rain and rainless belts. (4) State causes in each case. (5) What causes rain to fall upon oceans and plains?

3. Explain why clouds and rain should occur in front and center of low-pressure storms while sky is clear and cold in rear. (2) See Davis, page 228, and refer to diagrams of storms. (3) What effect has condensation of water vapor upon temperature? (4) Explain effect of rainfall upon temperature of western Washington.

4. Mention weather conditions favorable to formation of frost, ice, or snow. (2) Name some advantages of snow or ice as compared with rain. (3) Mention and give examples of advantages of snowfall to (a) water supply, (b) irrigation, (c) temperature, and (d) agriculture.

5. Mention kind of clouds that usually accompany low barometer and southwest winds. (2) What kind of weather do such clouds indicate? (3) Windy weather is indicated by what kind of cloud forms? (4) Cold weather with high barometer is usually accompanied by what kind of clouds? (5) Mention some uses of clouds.

III. REFERENCE BOOKS.

1. Dryer's Physical Geography, Chapter XXIII.
2. Tarr's Physical Geography, Chapter XII.
3. Story of Atmosphere, Chapters VII, VIII.
4. Moore's Descriptive Meteorology, Chapters XI, XII.
5. Waldo's Elementary Meteorology, Chapter V.
6. Davis's Elementary Meteorology, Chapter VIII.
7. Harrington's "Weather," Chapters X, XI, XII.
8. Salisbury's Physiography, Chapter XIV.

EXERCISE XX. THE OCEAN.**I. DIRECTIONS, ETC.**

1. Draw in red upon chart of world thermal lines showing temperature of surface water. (2) Read Tarr, pages 182-184, and see figure 320, Tarr, or page 253, Dryer. (3) Insert and explain beneath, table, page 254, Dryer. (4) Note from chart and table where temperature is greatest and where least. (5) Prepare explanation.

2. Give short description of (a) wind waves and (b) storm waves. (2) Include in description (a) cause, (b) size, and (c) effect of waves upon shore line. (3) Determine what is meant by (a) crest, (b) trough, (c) length, and (d) height of waves. (4) Use delta table for demonstration. (5) Note relation between size of waves and angle of wind. (6) Velocity of wind and force of waves.

3. Draw four diagrams showing relative position of (a) earth, (b) moon, and (c) sun at (a) neap and (b) spring tides. (2) See Appendix E, Tarr, or Dryer, page 263. (3) Explain each diagram by letters. (4) Indicate sun's gravity by red lines. (5) Note difference in height of tide at (a) new, (b) full, and (c) quarter moon, and prepare explanation. (6) See diagrams, page 511, Salisbury.

4. Draw upon chart of world cotidal lines in each ocean. (2) See Realm of Nature, page 258. (3) Note directions of tidal waves in each ocean. (4) Observe effect of continents upon direction and height of tidal waves.

5. Place upon chart of world ocean currents, warm in red and cold in black, with names in proper places. (2) See Dryer, page 257, or Tarr, page 194. (3) Note directions of drift of (a) warm and (b) cold currents. (4) Which way would currents flow if earth stood still? (5) If earth rotated from east to west? (6) Compare temperatures near eastern and western coasts of continents. (7) See thermal charts, and read Moore, page 266.

II. WRITTEN REVIEW.

1. State where sea water is (a) warmest and where (b) coldest. (2) Give reasons for each statement. (3) How do thermal lines upon ocean compare with thermal lines upon land? (4) Compare temperature of land with temperature of water in (a) summer and in (b) winter. (5) State how depth of water affects temperature. (6) See chart and table, and read Moore, pages 83-86.

2. Explain relation between (a) velocity of wind and force of waves, (b) angle of wind and size of waves. (2) Explain what is meant by (a) crest, (b) trough, (c) length, and (d) height of waves. (3) What is meant by (a) breakers and (b) undertow? (4) What effect have waves upon shore lines? Upon evaporation?

3. How are tides produced? (2) State what is meant by "tidal waves." (3) Give direction of tidal currents in north, south, and middle of each ocean. (4) Show how contents and shore lines affect (a) direction and (b) height of tidal water. (5) Explain how time of tides is determined. (6) Account for difference in time of tides in same and in different ports.

4. What causes ocean currents? (2) Of what importance are ocean currents to man? (3) Describe two currents, one warm and the other cold, in each ocean. (4) Give general effect of each current upon climate. (5) State effect of earth's rotation and continental masses upon direction of currents. (6) What effect have winds upon currents?

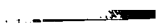
5. Record daily upon properly ruled paper conditions of tides in Tacoma for month, together with phases of moon. (2) See daily papers or tide tables, and observe tides daily in bay. (3) At what phase of moon is tide highest? (4) When is difference between high and low tides least? (5) How many feet difference between extreme high and low tides in Tacoma? (6) Show how tides assist in commerce.

III. REFERENCE BOOKS.

1. Tarr's Physical Geography, Chapter X.
2. Dryer's Physical Geography, Chapters XIX-XXI.
3. Salisbury's Physiography, Chapter XX.
4. Pilot Charts, Tide Tables.
5. Realm of Nature, Chapters X, XI.
6. Maury's Geography of Sea.
7. Shaler's Sea and Land.
8. Newcomb's Astronomy.







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WEATHER BUREAU.

THE RELATION BETWEEN THE PRECIPITATION
OVER THE WATERSHED OF THE OHIO RIVER
ABOVE AND THE STREAM-FLOW
AT CINCINNATI.

BY

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PROFESSOR OF METEOROLOGY.

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LETTER OF TRANSMITTAL.

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Washington, D. C., September 20, 1911.

The SECRETARY OF AGRICULTURE,
Washington, D. C.

SIR: I have the honor to transmit herewith a paper by Prof. J. Warren Smith, of the Weather Bureau, on the Stream Flow of the Ohio River at Cincinnati and Precipitation, and to recommend its publication as a Weather Bureau bulletin, the edition to consist of 2,500 copies.

Very respectfully,

WILLIS L. MOORE,
Chief United States Weather Bureau.

Approved.

JAMES WILSON,
Secretary of Agriculture.

(3)

STREAM-FLOW OF THE OHIO RIVER AT CINCINNATI AND PRECIPITATION IN THE WATERSHED ABOVE CINCINNATI.

INTRODUCTION.

In the following paper the relation between the precipitation over the Ohio watershed above Cincinnati and the stream-flow in the Ohio River at Cincinnati is discussed.

The period covered is for 50 years, from 1861 to 1910, inclusive. The data are tabulated for each month of each year, for each month of 10-year and 25-year groups of years, and for combinations of months for each year of the entire period.

The precipitation data considered were obtained from seven stations in the Ohio River watershed above Cincinnati, the period of observations covering the 50 years from 1861 to 1910, inclusive. The data are complete for the 50 years at Cincinnati, Marietta, and Portsmouth, Ohio. At Lexington, Ky., the records extend from 1861 to 1876 and from 1887 to 1910, all inclusive, while from 1882 to 1886, inclusive, the records at Frankfort, Ky., were used. The record at Pittsburgh, Pa., extends from 1861 to 1866, and from 1872 to 1910, all inclusive, while from 1867 to 1871, inclusive, data from Canonsburg, Pa., were used. The data at Westerville, Ohio, were complete from 1861 to 1901, inclusive, while from 1902 to 1910, inclusive, those for the Ohio State University were used. In the place of North Lewisburg, Ohio, the data for Urbana, Ohio, were used for the years 1909 and 1910. In each instance where data from two stations were used, the places were not far apart, and there is probably no great difference in the precipitation.

It is unfortunate that there are no stations with long records in West Virginia or at other points south of the Ohio River. It is quite probable that the means obtained from the seven stations used do not always give the true average precipitation for the Ohio watershed above Cincinnati. Still, it was thought better to use the same stations running through the 50-year period than to consider data from other sources.

Chart No. 1 indicates the locations of the stations.

For the stream-flow data, instead of considering the average height of the water, we have tabulated the total number of days in each month when the river was between each 10-foot stage.

Inasmuch as navigation is satisfactory in the Ohio when the river at Cincinnati is between 10 and 40 feet, we have considered the low-water days as those below 10 feet, and the high-water days as those above 40 feet.

The flood stage is 50 feet at Cincinnati, but there is more or less trouble in navigating the stream when the river is above 40 feet because of strong currents, swirls, debris, and, in its season, ice.

The work of tabulation has been great, and we have tried to group the data in every possible way to show the relation of the factors under consideration. An effort has been made to make the study exhaustive, plain, and convincing.

It seems to the writer that the statements made in the conclusions following are proven beyond dispute, and that the question of increasing flood conditions and increasing low-water periods is fairly settled in the negative, so far as our available stream-flow data can settle it.

CONCLUSIONS.

1. River stages at Cincinnati depend upon the precipitation over the *whole* watershed above that city.

2. There has been a very slight decrease in flood days in recent years, with the same rainfall.

3. The same amount of rainfall causes a better flow of water in the river during the low-water period than formerly. The number of low-water days was 14 per cent less during the past 25 years than during the preceding 25, calculating for the same rainfall. During the 10 years ending with 1910 the tendency for low water, with an equivalent rainfall, was not so great as for any preceding 10-year period for the past 50 years.

4. Floods do not occur at Cincinnati during February and March unless the precipitation for these months is in excess of the normal, except on *very* rare occasions. The number of flood days increase most rapidly when the precipitation during these months is about 3 inches above the normal or about one-half more than the normal.

EXPLANATION AND DISCUSSION OF TABLES.

TABLE NO. 1.

In this table there is given for each month of each year from 1861 to 1910, inclusive, the total number of days that the river at Cincinnati, Ohio, was below 5 feet, between 5 and 5.9 feet, 10 and 19.9 feet, 20 and 29.9 feet, 30 and 39.9 feet, etc., up to the highest water recorded.

These figures were obtained from the published daily river reading tables. By inspection of the table the high and low water months can be determined.

For example, in January, 1897, the water did not go above 20 feet during the month, the only January in the 50 years when this was true. On the other hand, the river reading was at no time below 20 feet in January, 1870, 1882, 1889, 1891, and 1907. The river has been above 60 feet on only 6 days in January, and this in 1907.

There are some interesting periodicities or combinations indicated. For example, there seemed to be increasing flood conditions in February, 1881 to 1884, and again from February, 1888 to 1891, but in the succeeding years the river was back to below normal height.

The river did not go above 20 feet in June from 1871 to 1879, inclusive. September seems to be a month of extremes; on a few years the river has not gone above 5 feet during the entire month, and in 2 cases the readings were all above 10 feet.

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
JANUARY.	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861			15	8	6	2			
1862			12	6	3	4	6		
1863			15	4	11	1			
1864		6	16	9					
1865			8	14	9				
1866			9	14	8				
1867			26	5					
1868			16	6	6	3			
1869			7	9	15				
1870				15	6	4	6		
1871		14	10	4	3				
1872		11	15	5					
1873			10	17	4				
1874			5	10	10	6			
1875		5	18	4	4				
1876			7	9	4	10	1		
1877			13	4	5	4	5		
1878		4	10	17					
1879			13	6	12				
1880			1	19	8	3			
1881		5	8	13	5				
1882				2	6	23			
1883			20	9	2				
1884			10	13	8				
1885			11	12	3	5			
1886			9	17	5				
1887			17	9	2	3			
1888		4	12	9	6				
1889				26	5				
1890			2	9	14	6			
1891				17	8	6			
1892			12	13	4	2			
1893		5	24	2					
1894			29	2					
1895		5	1	10		5			
1896		11	12	8					
1897		1	30						
1898			9		6	11	5		
1899			2	12	9	8			
1900		7	9	10	5				
1901		4	20	7					
1902		6	14	4	5	2			
1903			12	13	6				
1904			21	4	2	4			
1905		1	25	5					
1906			5	17	9				
1907				3	9	8	5	6	
1908			14	17					
1909		1	21	9					
1910		2	5	7	9	8			

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
FEBRUARY.									
1861.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
1862.			7	11	10				
1863.			3	4	11	10			
1864.			1	10	16	1			
1865.		7	11	11					
1866.			12	13	1	2			
1867.			13	11	4				
1868.			2	5	6	8	7		
1869.		3	23	3					
1870.			4	21	3				
1871.			10	10	8				
1872.			7	19	2				
1873.		9	17	3					
1874.			6	7	12	3			
1875.			7	10	6	5			
1876.	4	16	7	7	1				
1877.		3	7	9	9	10			
1878.	1	18	6	3					
1879.		3	23	2					
1880.		4	17	5	2				
1881.		12	7	3	3		4		
1882.		7	5	7	7		2		
1883.			4	4	11		9		
1884.			5	5	2		9		
1885.			2	2	6		6	11	2
1886.		4	17	7					
1887.			5	14	8	1			
1888.						18	10		
1889.		3	8	18					
1890.			12	9	7				
1891.				3	12	10	3		
1892.					2	18	8		
1893.			7	22					
1894.				4	10	6	8		
1895.			5	12	11				
1896.			28	13	5				
1897.			11	5	7	6	4	2	
1898.			4	7	12				
1899.			9	7	12				
1900.			8	12	8				
1901.		4	23	1					
1902.		8	9	5	4	2			
1903.				4	10	14			
1904.			16	11	2				
1905.		7	5	12	4				
1906.		3	21	4					
1907.			11	14	3				
1908.			3	12	5	7	2		
1909.			9	5	9	1	4		
1910.			7	12	8	1			
MARCH.									
1861.			10	21					
1862.				7	18	6			
1863.				5	23	3			
1864.			13	18					
1865.				2	10	14	5		
1866.			2	11	18				
1867.				3	9	7	12		
1868.				9	10	10			
1869.			2	14	8	2			
1870.			7	26	3	2			
1871.				26	5				
1872.		5	24	2					
1873.			16	11	4				
1874.			7	16	8				
1875.				5	21	5			
1876.			11	11	8	1			
1877.		1	7	7	13	3			
1878.			7	13	6				
1879.				11	20				
1880.				15	9	7			
1881.				26	5				
1882.				10	15	6			
1883.				13	18				
1884.			3	5	8	15			
1885.		4	19	8					

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
MARCH—continued.	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1886.			18	7	5	1			
1887.			12	4	8	4	3		
1888.			13	12	6				
1889.			14	17					
1890.				3	4	12	12		
1891.					21	10			
1892.			4	19	8				
1893.			2	22	7				
1894.			8	23					
1895.			3	17	11				
1896.			17	3	11				
1897.					17	12	2		
1898.			13	6	2	3	5	2	
1899.				5	13	6	7		
1900.			1	16	14				
1901.		7	2	15	7				
1902.			4	4	8	11	4		
1903.				3	9	11	8		
1904.			1	11	5	14			
1905.			3	12	5	11			
1906.			6	13	11	1			
1907.				14	2	4	7	4	
1908.				2	10	13	6		
1909.			6	8	9	6	2		
1910.			12	4	3	9	3		
APRIL.									
1861.			5	12	6	7			
1862.				9	6	9	6		
1863.			12	16	3				
1864.			1	22	7				
1865.			5	8	11	6			
1866.			2	19	9				
1867.				25	5				
1868.			4	12	12	2			
1869.				20	4	6			
1870.				10	7	13			
1871.			18	12					
1872.		4	8	3	10	5			
1873.			4	11	15				
1874.			4	6	14	6			
1875.			11	12	7				
1876.			6	19	4	1			
1877.			9	17	4				
1878.			28	2					
1879.			15	10	5				
1880.			13	12	2	3			
1881.				18	9	3			
1882.			22	8					
1883.				8	13	9			
1884.			9	13	8				
1885.		1	5	14	10				
1886.			8	4	2	4	12		
1887.			17	4	4	5			
1888.			11	12	7				
1889.			22	8					
1890.			1	12	16	1			
1891.			5	8	11	6			
1892.				16	8	6			
1893.			5	17	7	1			
1894.			15	15					
1895.			7	14	9				
1896.			13	8	3	6			
1897.			5	14	11				
1898.			6	17	2		3		
1899.			10	12	4	2	2		
1900.			23	7					
1901.				8	12	2	8		
1902.			8	14	5	3			
1903.				11	14	5			
1904.			11	8	6	5			
1905.			18	11	1				
1906.			6	15	3	5	1		
1907.				29	1				
1908.				10	11	5	4		
1909.			4	21	5				
1910.			24	6					

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
MAY.	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861			10	14	7				
1862			22	7	2				
1863		4	16	11					
1864			15	10	6				
1865			5	9	9	6	2		
1866		5	22	4					
1867			11	17	3				
1868			6	10	13	2			
1869			12	14	5				
1870			28	3					
1871		3	11	10	6	1			
1872		8	23						
1873			10	12	9				
1874		7	12	5	3	4			
1875		6	21	4					
1876			23	8					
1877			21	10					
1878			9	21	1				
1879		10	21						
1880		12	11	4	2	2			
1881		2	21	8					
1882			1	13	13	4			
1883			17	14					
1884			25	6					
1885			30	1					
1886			17	6	8				
1887		3	10	14	4				
1888		5	26						
1889			25	6					
1890			10		14	7			
1891		20	11						
1892			5	20	6				
1893			1	10	9	9	2		
1894		2	22	4	3				
1895			31						
1896		10	21						
1897			11	16	4				
1898			2	29					
1899			20	11					
1900		6	25						
1901			12	9	7	2	1		
1902		4	27						
1903		12	16	3					
1904			17	9	5				
1905			15	7	3	6			
1906		7	22	2					
1907			10	20	1				
1908				19	6	6			
1909			9	11	4	7			
1910			19	12					
JUNE.									
1861		12	14	4					
1862			24	6					
1863	6	24							
1864		11	19						
1865			28	2					
1866	2	26							
1867		1	21	8					
1868		3	20	7					
1869			18	12					
1870		2	23	5					
1871		27	3						
1872		12	18						
1873		23	7						
1874		30							
1875		4	26						
1876		15	15						
1877		10	20						
1878		9	21						
1879		25	5						
1880		5	20	5					
1881		8	15	4	3				
1882			10	10	10				
1883			13	14	3				
1884			8	22					
1885		4	22	4					

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
JUNE—continued.	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1886.....		2	24	4					
1887.....		9	15	6					
1888.....		19	11						
1889.....			5	20	5				
1890.....			24	4	2				
1891.....			18	12					
1892.....			13	13	4				
1893.....			26	4					
1894.....		11	18	1					
1895.....	5	24	1						
1896.....		6	21	3					
1897.....		6	23	1					
1898.....		9	21						
1899.....			30						
1900.....		16	14						
1901.....			4	15	9	2			
1902.....		15	14	1					
1903.....			30						
1904.....		4	16	10					
1905.....			24	6					
1906.....		3	27						
1907.....			7	13	7	3			
1908.....		4	26						
1909.....			16	14					
1910.....			11	17	2				
JULY.									
1861.....		31							
1862.....		8	23						
1863.....		24	7						
1864.....	18	13							
1865.....		9	21	1					
1866.....		18	10	3					
1867.....		26	3						
1868.....		31							
1869.....			16	15					
1870.....		17	14						
1871.....		31							
1872.....		11	20						
1873.....		6	23	2					
1874.....	10	19	2		14				
1875.....			13	4					
1876.....		8	23						
1877.....		11	20						
1878.....		22	9						
1879.....	8	23							
1880.....		14	17						
1881.....		25	6						
1882.....		2	18	11					
1883.....			29						
1884.....	1	17	13						
1885.....	2	27	2						
1886.....		6	21	4					
1887.....	8	23							
1888.....		12	12	5	2				
1889.....			21	10					
1890.....		18	13						
1891.....		3	28						
1892.....		10	21						
1893.....		21	10						
1894.....	15	16							
1895.....	4	24	3						
1896.....		1	14	10	4	2			
1897.....		6	19	6					
1898.....		25	6						
1899.....		26	5						
1900.....		22	9						
1901.....		4	25	2					
1902.....			16	15					
1903.....		2	29						
1904.....		8	19	4					
1905.....			28	3					
1906.....		17	14						
1907.....			20	11					
1908.....		19	12						
1909.....		9	21	1					
1910.....		5	20	6					

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
AUGUST.	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861.		11	20						
1862.	15	16							
1863.	5	26							
1864.	18	3	10						
1865.		13	18						
1866.	2	20	9						
1867.	1	30							
1868.		21	10						
1869.		22	9						
1870.		9	22						
1871.	12	19							
1872.		23	8						
1873.		12	19						
1874.		24	7						
1875.		1	16	3	2	4	5		
1876.		15	13						
1877.	17	14							
1878.		17	14						
1879.		18	13						
1880.		21	10						
1881.	13	18							
1882.		11	19	1					
1883.	1	20	10						
1884.	9	18	4						
1885.		3	28						
1886.		14	17						
1887.	19	12							
1888.		20	5	3	3				
1889.		10	21						
1890.		21	8	2					
1891.		12	19						
1892.		28	3						
1893.	16	15							
1894.	30	1							
1895.		31							
1896.			21	3	5	2			
1897.		20	11						
1898.			18	8	5				
1899.	5	19	7						
1900.	2	24	5						
1901.		14	17						
1902.		18	13						
1903.		31							
1904.		31							
1905.		3	28						
1906.		5	24	2					
1907.		5	22	4					
1908.		24	7						
1909.		19	12						
1910.	17	14							
SEPTEMBER.									
1861.		22	7	1					
1862.	30								
1863.	30								
1864.		3	27						
1865.		8	18	4					
1866.		7	12	4	5	2			
1867.	22	8							
1868.		10	7	8	3	2			
1869.		19	7	4					
1870.	6	20	4						
1871.	15	15							
1872.		14							
1873.		11	5						
1874.		22	8						
1875.	18	12							
1876.		12	6	9	3				
1877.	7	23							
1878.		18	5	3	4				
1879.	8	16	6						
1880.	5	25							
1881.	24	6							
1882.			30						
1883.	29	1							
1884.	30								
1885.		12	18						

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
SEPTEMBER—continued.	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1886.....	11	19							
1887.....	30								
1888.....		2	24	4					
1889.....		28	2						
1890.....			15	10	5				
1891.....		17	13						
1892.....	3	27							
1893.....	5	20	5						
1894.....	24	2	4						
1895.....	16	14							
1896.....		30							
1897.....	17	13							
1898.....		29	1						
1899.....	14	16							
1900.....	17	13							
1901.....		12	18						
1902.....	27	3							
1903.....		22	8						
1904.....	18	12							
1905.....		14	16						
1906.....		16	14						
1907.....		1	29						
1908.....	25	5							
1909.....		30							
1910.....	3	26	1						
OCTOBER.									
1861.....			17	9	3	2			
1862.....	31								
1863.....	25	6							
1864.....		9	18	4					
1865.....		25	6						
1866.....		5	17	6	3				
1867.....	31								
1868.....		20	7	3	1				
1869.....		24	7						
1870.....	6	25							
1871.....	31								
1872.....	24	7							
1873.....	23	1	3	4					
1874.....	16	15							
1875.....		31							
1876.....	1	16	14						
1877.....	15	16							
1878.....	16	10	5						
1879.....	31								
1880.....	20	11							
1881.....	26	5							
1882.....		21	10						
1883.....		24	7						
1884.....	28	3							
1885.....	11	6	14						
1886.....	17	14	29						
1887.....	31								
1888.....		11	5	11	4				
1889.....		24	7						
1890.....			15	12	4				
1891.....	18	13							
1892.....	28	3							
1893.....		15	16						
1894.....	23	8							
1895.....	31								
1896.....		2	25	4					
1897.....	31								
1898.....	4	18	4	5					
1899.....	31								
1900.....	27	3	1						
1901.....	3	28							
1902.....	3	24	4						
1903.....	10	17	4						
1904.....	31								
1905.....		19	11	1					
1906.....			31						
1907.....		18	13						
1908.....	27	4							
1909.....	15	15	1						
1910.....	7	17	7						

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
NOVEMBER.	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861			13	16	1				
1862	19	8	3						
1863		22	8						
1864		2	8	20					
1865		16	14						
1866		1	12	17					
1867	11	19							
1868		5	25						
1869		23	7						
1870		25	5						
1871	20	4	6						
1872		17	13						
1873		4	18	8					
1874	26	1	3						
1875		6	19	5					
1876		8	22						
1877		16	10	1	3				
1878		4	21	3	2				
1879	20	5	5						
1880		14	16						
1881		6	18	6					
1882		30							
1883			26	4					
1884	24	6							
1885			29	1					
1886	13	4	5	7	1				
1887	28	2							
1888			3	17	10				
1889			11	10	9				
1890			8	18	4				
1891	2	19	5	4					
1892	11	19							
1893		18	12						
1894	7	23							
1895	26	4							
1896		1	27	2					
1897	8	11	11						
1898			22	8					
1899	8	22							
1900	6	17	3	1	3				
1901	20	9	1						
1902	3	24	3						
1903	11	12	7						
1904	25	5							
1905			29	1					
1906		8	13	5	4				
1907		2	17	11					
1908	21	9							
1909		29	1						
1910	4	26							
DECEMBER.									
1861			22	5	4				
1862		23	8						
1863		6	19	6					
1864			12	11	3	5			
1865		11	10	1	7	2			
1866			3	19	9				
1867	8	7	10	4	2				
1868			18	13					
1869			8	12	11				
1870		1	30						
1871	1	24	6						
1872		19	11	1					
1873			5	14	8	4			
1874		3	27	1					
1875			10	16	1	4			
1876		7	24						
1877			25	6					
1878			6	11	11	3			
1879		7	15	2	5	2			
1880		3	18	3	7				
1881			15	1	13	2			
1882		6	25						
1883			23	1	1	6			
1884	4	8	17	2					
1885			22	8	1				

TABLE 1.—Number of days during each month and year when the river reading at Cincinnati, Ohio, was between the heights indicated, 1861 to 1910—Continued.

Years.	0 to 4.9 feet.	5 to 9.9 feet.	10 to 19.9 feet.	20 to 29.9 feet.	30 to 39.9 feet.	40 to 49.9 feet.	50 to 59.9 feet.	60 to 69.9 feet.	70 to 79.9 feet.
DECEMBER—continued.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
1866.....			15	16					
1867.....	4	27							
1868.....			26	5					
1869.....			4	27					
1870.....			24	5	2				
1871.....			21	10					
1872.....		18	13						
1873.....		2	22	7					
1874.....		11	20						
1875.....	1	22	7	1					
1876.....			16	15					
1877.....			23	8					
1878.....			22	6	3				
1879.....			15	9	7				
1880.....			9	8	10	3	1		
1881.....			20	4	7				
1902.....			12	10	2	7			
1903.....		21	9	1					
1904.....	24	6							
1905.....			7	16	7	1			
1906.....			13	9	9				
1907.....			15	12	4				
1908.....	12	14	5						
1909.....		23	8						
1910.....		16	13	2					

TABLE No. 2.

This table gives the average precipitation for the watershed for each month, together with the averages for each 10 years, for each 25 years, and for the whole 50 years.

TABLE 2.—Average precipitation in the Ohio watershed above Cincinnati, 1861 to 1910, inclusive.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1861.....	2.5	2.0	2.3	4.5	5.0	3.5	3.5	4.5	3.3	3.6	4.0	1.2	39.9
1862.....	5.4	3.1	4.6	5.6	3.2	3.3	3.6	2.2	1.1	1.7	2.9	3.1	39.8
1863.....	6.2	3.5	3.6	2.0	2.4	2.7	2.4	2.9	2.1	3.7	2.5	3.2	37.2
1864.....	1.8	1.4	2.6	2.5	3.2	2.4	1.5	5.4	4.9	2.4	4.4	3.7	36.2
1865.....	2.6	2.4	5.0	4.5	7.3	4.3	5.8	3.8	5.9	1.5	0.9	4.8	48.8
1866.....	3.5	2.5	3.7	2.7	1.3	4.5	5.5	3.9	10.1	3.2	4.1	2.2	47.2
1867.....	2.4	5.0	5.0	2.7	4.0	3.2	3.9	2.8	0.8	3.0	2.1	4.2	39.1
1868.....	3.1	1.2	5.3	3.6	5.5	4.8	3.1	4.8	7.6	1.5	2.0	2.2	44.7
1869.....	2.9	2.9	4.2	2.9	4.6	3.9	4.5	2.2	4.0	2.0	3.6	3.1	40.8
1870.....	6.2	3.1	4.2	2.5	1.9	3.7	4.4	3.1	1.4	2.9	1.8	2.3	37.5
1871.....	2.1	2.7	2.6	2.0	2.8	3.3	3.0	4.4	1.3	1.8	2.7	2.6	31.3
1872.....	0.9	1.9	1.5	4.7	2.9	2.7	6.2	3.1	1.6	2.5	1.0	2.5	31.5
1873.....	2.5	3.6	3.1	2.9	3.8	3.5	5.7	3.8	2.3	4.5	2.1	5.0	42.8
1874.....	4.2	4.1	3.5	5.2	1.3	2.8	5.1	2.4	2.7	0.5	3.9	3.5	39.2
1875.....	1.7	1.8	4.0	1.7	3.2	5.0	8.9	3.1	2.1	2.6	4.3	3.6	42.0
1876.....	6.1	2.5	3.8	2.7	2.6	3.5	7.0	3.5	5.6	2.4	2.4	1.4	43.5
1877.....	2.9	0.7	5.3	2.7	2.3	5.6	4.0	1.8	2.2	1.9	3.5	2.4	36.3
1878.....	3.0	1.7	3.0	2.4	2.6	3.9	4.2	3.2	4.2	2.7	3.2	3.6	37.7
1879.....	3.0	2.8	4.3	1.0	2.2	4.3	4.4	6.1	2.8	0.8	3.2	4.7	36.6
1880.....	4.3	4.2	3.8	5.5	3.2	4.8	2.9	4.6	2.6	2.3	3.0	3.2	44.4
1881.....	2.9	3.4	3.8	2.4	2.2	4.4	4.1	1.6	2.5	4.7	3.6	5.0	40.0
1882.....	5.9	5.3	4.8	2.9	7.7	5.5	3.0	5.0	3.3	1.8	1.6	1.9	43.7
1883.....	2.9	7.3	2.9	4.2	5.0	4.6	3.7	1.6	2.3	5.4	3.5	4.5	47.9
1884.....	3.8	6.1	4.1	2.5	4.0	2.8	3.0	1.5	3.9	1.4	1.4	4.1	38.6
1885.....	5.3	2.3	1.0	3.6	3.7	3.6	2.3	5.8	2.6	3.6	2.6	1.8	38.2
1886.....	3.7	1.8	3.3	3.0	5.0	4.2	3.4	3.4	3.6	1.1	4.6	2.5	39.6
1887.....	2.7	7.3	2.1	5.1	3.6	3.5	3.5	2.4	2.5	0.5	2.6	2.7	32.6
1888.....	4.7	1.8	4.3	2.1	3.7	2.5	5.2	8.1	2.1	4.1	4.5	1.5	44.0
1889.....	3.8	1.6	1.3	2.0	3.5	3.9	5.7	1.3	4.0	2.1	4.7	2.5	38.4

TABLE 2.—Average precipitation in the Ohio watershed above Cincinnati, 1861 to 1910, inclusive—Continued.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>
1890.....	5.3	5.9	6.4	3.3	4.9	4.5	2.3	5.1	5.6	3.9	2.6	3.5	53.3
1891.....	3.4	4.9	5.1	2.2	2.2	4.9	4.8	3.1	1.8	1.6	4.8	2.4	41.2
1892.....	2.4	3.1	3.0	4.3	5.2	4.8	4.2	3.0	3.0	0.5	2.6	2.0	38.1
1893.....	2.9	5.4	2.0	6.5	4.4	4.0	3.0	2.0	2.2	4.5	2.3	2.6	41.8
1894.....	2.5	3.7	2.2	3.0	3.6	3.0	1.9	2.8	2.9	1.5	1.9	3.4	32.4
1895.....	5.0	0.7	2.4	2.4	2.1	2.8	2.2	2.9	1.1	1.1	3.8	3.6	30.1
1896.....	1.6	2.6	4.1	1.9	3.1	4.3	9.1	3.7	4.8	1.8	3.1	1.7	41.8
1897.....	2.1	5.3	6.0	4.0	3.9	3.4	5.5	2.4	1.0	0.4	6.3	3.4	43.4
1898.....	6.7	2.1	7.2	2.3	4.5	3.9	4.2	4.2	2.7	4.0	3.1	2.7	47.6
1899.....	4.1	2.7	5.7	1.8	4.2	3.4	3.6	2.6	2.7	2.0	1.9	3.0	37.7
1900.....	2.5	3.2	2.2	1.8	2.5	2.7	3.9	3.9	1.3	1.6	5.0	1.7	32.3
1901.....	1.6	1.1	2.6	4.3	3.7	4.7	2.4	3.5	2.3	0.6	1.4	4.0	32.2
1902.....	2.4	1.1	3.1	2.2	3.2	6.8	3.1	1.7	3.4	2.2	2.7	4.8	36.9
1903.....	2.3	5.7	4.2	3.4	2.6	3.9	3.2	2.1	1.2	2.2	2.1	1.8	34.7
1904.....	2.6	2.1	5.9	2.9	3.1	3.2	2.6	2.2	1.4	1.1	0.3	3.3	30.7
1905.....	2.0	1.7	3.5	3.2	6.0	4.4	3.4	4.6	3.2	4.7	2.7	2.8	42.2
1906.....	2.5	1.6	5.3	1.6	2.3	4.1	5.2	4.5	3.3	2.1	2.9	3.9	39.3
1907.....	7.4	1.2	5.8	2.8	3.3	4.6	6.1	2.9	2.6	2.2	2.1	2.9	43.9
1908.....	1.6	4.6	6.0	4.1	4.7	2.3	3.6	2.8	0.4	1.1	1.1	2.0	34.3
1909.....	1.2	5.9	3.0	4.6	4.2	6.0	4.1	2.8	2.0	2.3	1.6	2.6	40.3
1910.....	4.8	4.3	0.3	2.9	4.3	3.2	3.7	2.1	4.6	3.7	1.4	2.7	38.0
Mean.....	3.40	3.18	3.78	3.15	3.63	3.91	4.11	3.34	2.96	2.35	2.85	3.00	39.68
1861-1870.....	3.66	2.71	4.05	3.35	3.84	3.63	3.82	3.56	4.12	2.55	2.83	3.00	41.12
1871-1880.....	3.07	2.60	3.49	3.08	2.69	3.94	5.14	3.60	2.74	2.20	2.93	3.25	38.73
1881-1890.....	4.10	4.28	3.40	3.11	4.33	3.95	3.62	3.58	3.24	2.86	3.17	3.00	42.64
1891-1900.....	3.32	3.37	3.99	3.02	3.57	3.69	4.24	3.06	2.35	1.90	3.48	2.65	38.64
1901-1910.....	2.84	2.93	3.97	3.20	3.74	4.32	3.74	2.92	2.44	2.24	1.83	3.08	37.25
1861-1885.....	3.52	3.10	3.68	3.20	3.52	3.86	4.23	3.48	3.33	2.58	2.81	3.19	40.50
1886-1910.....	3.27	3.26	3.88	3.11	3.75	3.95	4.00	3.20	2.63	2.12	2.88	2.80	38.85

TABLE No. 3.

This table shows the departure of the monthly precipitation from the normal for each month and the departure of each 10-year and each 25-year average from the normal.

TABLE 3.—Departure of monthly precipitation from normals, Ohio watershed above Cincinnati, Ohio, 1861 to 1910, inclusive.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>
1861.....	-0.9	-1.2	-1.5	+1.3	+1.4	-0.4	-0.6	+1.2	+0.3	+1.2	+1.2	-1.8	+ 0.2
1862.....	+2.0	-0.1	+0.8	+2.4	-0.4	-0.6	-0.5	-1.1	-1.9	-0.7	+0.1	+0.1	+ 0.1
1863.....	+2.8	+0.3	-0.2	-1.2	-1.2	-1.2	-1.7	-0.4	-0.9	+1.3	-0.3	+0.2	- 2.5
1864.....	-1.6	-1.8	-1.2	-0.7	-0.4	-1.5	-2.6	+2.1	+1.9	+0.0	+1.6	+0.7	- 3.5
1865.....	-0.8	-0.8	+1.2	+1.3	+3.7	+0.4	+1.7	+0.5	+2.9	-0.9	-1.9	+1.8	+ 9.1
1866.....	+0.1	-0.7	-0.1	-0.5	-2.3	+0.6	+1.4	+0.6	+7.1	+0.8	-1.3	-0.8	+ 7.5
1867.....	+1.8	+1.2	-0.5	+0.4	-0.7	-0.2	-0.5	-2.2	+0.6	-0.7	+1.2	- 0.6	- 0.6
1868.....	-0.3	-2.0	+1.7	+0.4	+1.9	+0.9	-1.0	+1.5	+4.6	-0.9	-0.8	-0.8	+ 5.0
1869.....	-0.5	-0.3	+0.4	-0.3	+1.0	+0.0	+0.4	-1.1	+1.0	-0.4	+0.8	+0.1	+ 1.1
1870.....	+2.8	-0.1	+0.4	-0.7	-1.7	-0.2	+0.3	-0.2	-1.6	+0.5	+1.0	-0.7	- 2.2
1871.....	-1.3	-0.5	-1.2	-1.2	-0.8	-0.6	-1.1	+1.1	-1.7	-0.6	-0.1	-0.4	- 8.4
1872.....	-2.5	-1.3	-2.3	+1.5	-0.7	-1.2	+2.1	-0.2	-1.4	+0.1	-1.8	-0.5	- 8.2
1873.....	-0.9	+0.4	-0.7	-0.3	+0.2	-0.4	+1.6	+0.5	-0.7	+2.1	-1.7	+2.0	+ 3.1
1874.....	+0.8	+0.9	-0.3	-2.0	-2.3	-1.1	+1.0	-0.9	-0.3	-1.9	+1.1	+0.5	- 0.5
1875.....	-1.7	-1.4	+0.2	+1.5	-0.4	+1.1	+4.8	-0.2	-0.9	+0.2	+1.5	+0.6	+ 2.3
1876.....	+2.7	-0.7	+0.0	-0.5	-1.0	-0.4	+2.9	+0.2	+2.6	+0.0	-0.4	-1.6	+ 3.8
1877.....	-0.5	-2.5	+1.7	-0.5	-1.3	+1.7	-0.1	-1.5	-0.8	-0.5	+0.7	-0.6	- 4.4
1878.....	-0.4	-1.5	-0.8	-0.8	-1.0	+0.0	+0.1	-0.1	+1.2	+0.3	+0.4	+0.6	- 2.0
1879.....	-0.4	-0.4	+0.5	-2.2	-1.4	+0.4	+0.3	+2.8	-0.2	-1.6	+0.4	+1.7	- 0.1
1880.....	+0.9	+1.0	+0.0	+2.3	-0.4	+0.9	-1.2	+1.3	-0.4	-0.1	+0.2	+0.2	+ 4.7
1881.....	-0.5	+0.2	+0.0	-0.8	-1.4	+0.5	+0.0	-1.7	-0.5	+2.3	+0.8	+2.0	+ 0.9
1882.....	+2.5	+2.1	+1.0	-0.3	+4.1	+1.6	-1.1	+1.7	+0.3	-0.6	-1.2	-1.1	+ 9.2
1883.....	-0.5	+4.1	-0.9	+1.0	+1.4	+0.7	-0.4	-1.7	-0.7	+3.0	+0.7	+1.5	+ 8.0

TABLE 3.—Departure of monthly precipitation from normals, Ohio watershed above Cincinnati, Ohio, 1861 to 1910, inclusive—Continued.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>	<i>In.</i>
1884	+0.4	+2.9	+0.3	-0.7	+0.4	-1.1	-1.1	-1.8	+0.9	+1.0	-1.4	+1.1	-1.1
1885	+1.9	-0.9	-2.8	+0.4	+0.1	-0.3	-1.8	+2.5	-0.4	-1.2	-0.2	-1.2	-1.5
1886	+0.3	-1.4	-0.5	-0.2	+1.4	+0.3	-0.7	+0.1	+0.6	-1.3	+1.8	-0.5	-0.1
1887	-0.7	+4.1	-1.7	+1.9	±0.0	-0.4	-0.6	-0.9	-0.5	-1.9	-0.2	-0.3	-1.2
1888	+1.3	-1.4	+0.5	-1.1	+0.1	-1.4	+1.1	+4.8	-0.9	+1.7	+1.7	-1.5	+4.9
1889	+0.4	-1.6	-2.5	-1.2	-0.1	±0.0	+1.6	-2.0	+1.0	-1.3	+1.9	-0.5	-3.3
1890	+1.9	+2.7	+2.6	+0.1	+1.3	+0.6	-1.8	+1.8	+2.6	+1.5	-0.2	+0.5	+13.6
1891	±0.0	+1.7	+1.3	-1.0	-1.4	+1.0	+0.7	-0.2	-1.2	-0.8	+2.0	-0.6	+1.5
1892	-1.0	-0.1	-0.8	+1.1	+1.6	+0.9	+0.1	-0.3	±0.0	-1.9	-0.2	-1.0	-1.6
1893	-0.5	+2.2	-1.8	+3.3	+0.8	+0.1	-1.1	-1.3	-0.8	+2.1	-0.5	-0.4	+2.1
1894	-0.9	+0.5	-1.6	-0.2	±0.0	-0.9	-2.2	-0.5	-0.1	-0.9	-0.9	+0.4	-7.3
1895	+1.6	-2.5	-1.4	-0.8	-1.4	-1.1	-1.9	-0.4	-1.9	-1.3	+1.0	+0.6	-9.6
1896	-1.8	-0.6	+0.3	-1.3	-0.5	+0.4	+5.0	+0.4	+1.8	-0.6	+0.3	-1.3	+2.1
1897	-1.3	+2.1	+2.2	+0.8	+0.3	-0.8	+1.4	-0.9	-2.0	-2.0	+3.5	+0.4	+3.7
1898	+3.3	-1.1	+3.4	-0.9	+0.9	±0.0	+0.1	+0.9	-0.3	+1.6	+0.3	-0.3	+7.9
1899	+0.7	-0.5	+1.9	-1.4	+0.6	-0.5	-0.5	-0.7	-0.3	-0.4	+0.9	±0.0	-2.0
1900	-0.9	±0.0	-1.6	-1.4	-1.1	-1.2	-0.3	+0.6	-1.7	-0.8	+2.2	-1.3	-7.4
1901	-1.8	-2.1	-1.1	+1.1	+0.1	+0.8	-1.7	+0.2	-0.7	-1.8	-1.4	+1.0	-7.5
1902	-1.0	-2.1	-0.7	-1.0	-0.4	+2.9	-1.0	-1.6	+0.4	±0.0	-0.1	+1.8	-2.8
1903	-1.1	+2.5	+0.4	+0.2	-1.0	±0.0	-0.9	-1.2	-1.8	-0.2	-0.7	-1.2	-5.0
1904	-0.8	-1.1	+2.1	-0.3	-0.5	-0.7	-1.5	-1.1	-1.6	-1.3	-2.5	+0.3	-9.0
1905	-1.4	-1.5	-0.3	±0.0	+2.4	+0.5	-0.7	+1.3	+0.2	+2.3	-0.1	-0.2	+2.5
1906	-0.9	-1.6	+1.5	-1.6	-1.3	+0.2	+1.1	+1.2	+0.3	-0.3	+0.1	+0.9	-0.4
1907	+4.0	-2.0	+2.0	-0.4	-0.3	+0.7	+2.0	-0.4	-0.4	-0.2	-0.7	-0.1	+4.2
1908	-1.8	+1.4	+2.2	+0.9	+1.1	-1.6	-0.5	-0.5	-2.6	-1.3	-1.7	-1.0	-5.4
1909	-2.2	+2.7	-0.8	+1.4	+0.6	+2.1	±0.0	-0.5	-1.0	-0.1	-1.2	-0.4	+0.6
1910	+1.4	+1.1	-3.5	-0.3	+0.7	-0.7	-0.4	-1.2	+1.6	+1.3	-1.4	-0.3	-1.7
1861-1870	+0.3	-0.5	+0.2	+0.2	+0.2	-0.3	-0.3	+0.3	+1.1	+0.2	±0.0	±0.0	+1.5
1871-1880	-0.3	-0.6	-0.3	-0.1	-0.9	±0.0	+1.0	+0.3	-0.3	-0.2	+0.1	+0.2	-1.3
1881-1890	+0.7	+1.1	-0.4	-0.1	+0.7	+0.1	-0.5	+0.3	-0.2	+0.5	+0.4	±0.0	+3.0
1891-1900	-0.1	+0.2	+0.2	-0.2	±0.0	-0.2	+0.1	-0.2	-0.6	-0.5	+0.7	-0.4	-1.0
1901-1910	-0.6	-0.3	+0.2	±0.0	+0.1	+0.4	-0.4	-0.4	-0.6	-0.2	-1.0	+0.1	-2.7
1861-1885	+0.1	-0.1	-0.1	±0.0	-0.1	±0.0	+0.1	+0.2	+0.4	+0.2	±0.0	+0.2	+0.8
1886-1910	-0.1	+0.1	+0.1	-0.1	+0.2	+0.1	-0.1	-0.1	-0.4	-0.3	+0.1	-0.2	-0.8

TABLE NO. 4.

The number of days that the river stages were between each 5 or 10 feet for each month and the year for each 10-year period is shown in Table 5, together with the totals for the 50 years and the means for each 10-year period. The yearly averages can be obtained by dividing the 10-year averages by 10.

If it is true that the cutting away of the forests has increased flood conditions and intensified low-water periods, it seems to the writer that there would be a regular increase in the low-water days in the months of July, August, and September, and that this increase would appear in the 10-year periods in the table. On the contrary, there were only 64 days from 1901 to 1910, inclusive, when the river was between 5 and 10 feet during the month of July, as compared with 179 days from 1861 to 1870, inclusive. In October there were only 96 days in the 10 years from 1901 to 1910, inclusive, when the river was below 5 feet, as compared with 177 days in the 10 years from 1871 to 1880, inclusive. The high-water days should show a regular increase also during the months from January to April, inclusive, but such is not the case.

TABLE 4.—Total number of days in each month with river readings between values indicated at Cincinnati, 10-year periods, 1861 to 1910, inclusive.

0 TO 4.9 FEET.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861-1870.....	0	0	0	0	0	8	18	41	88	93	30	8	286
1871-1880.....	0	0	0	0	0	0	18	29	100	177	66	1	391
1881-1890.....	0	0	0	0	0	0	11	42	124	113	65	8	363
1891-1900.....	0	0	0	0	0	5	19	53	96	193	68	1	435
1901-1910.....	0	0	0	0	0	0	0	17	73	96	84	36	306

5 TO 9.9 FEET.

1861-1870.....	6	10	0	0	9	81	179	171	97	114	121	48	836
1871-1880.....	34	14	6	4	46	160	145	167	159	107	79	63	984
1881-1890.....	9	7	4	1	10	50	132	147	68	108	48	41	626
1891-1900.....	29	0	0	0	38	72	154	150	181	62	134	79	899
1901-1910.....	14	22	7	0	23	26	64	164	141	142	124	80	807

10 TO 19.9 FEET.

1861-1870.....	124	86	34	29	147	167	94	98	82	72	95	140	1,168
1871-1880.....	102	93	72	116	162	135	127	100	22	22	133	147	1,281
1881-1890.....	89	49	79	95	172	161	135	112	89	58	100	171	1,310
1891-1900.....	128	81	48	89	149	185	115	84	23	46	80	161	1,189
1901-1910.....	137	104	34	71	147	175	204	123	86	71	71	108	1,326

20 TO 29.9 FEET.

1861-1870.....	90	99	116	152	99	44	19	0	21	22	53	71	786
1871-1880.....	96	106	122	104	74	5	6	3	12	4	17	54	603
1881-1890.....	119	67	105	101	78	66	30	6	14	23	63	65	737
1891-1900.....	74	82	111	128	90	34	16	11	0	9	15	64	634
1901-1910.....	86	80	86	133	92	76	42	6	0	1	17	54	673

30 TO 39.9 FEET.

1861-1870.....	64	59	99	70	45	0	0	0	8	7	1	36	389
1871-1880.....	50	43	94	61	21	0	14	2	7	0	5	32	329
1881-1890.....	56	45	69	69	39	23	2	3	5	8	24	17	360
1891-1900.....	42	67	104	55	22	4	4	10	0	0	3	6	317
1901-1910.....	40	45	69	58	26	18	0	0	0	0	4	29	289

40 TO 49.9 FEET.

1861-1870.....	14	21	44	43	8	0	0	0	4	2	0	7	143
1871-1880.....	23	23	16	15	7	0	0	4	0	0	0	13	101
1881-1890.....	37	55	38	22	11	0	0	0	0	0	0	8	171
1891-1900.....	32	30	31	23	9	0	2	2	0	0	0	1	130
1901-1910.....	22	25	80	25	21	5	0	0	0	0	0	8	186

50 TO 59.9 FEET.

1861-1870.....	12	7	17	6	2	0	0	0	0	0	0	44
1871-1880.....	6	4	0	0	0	0	0	5	0	0	0	15
1881-1890.....	0	39	15	12	0	0	0	0	0	0	0	66
1891-1900.....	5	20	14	5	2	0	0	0	0	0	0	46
1901-1910.....	5	6	30	13	1	0	0	0	0	0	0	55

60 TO 69.9 FEET.

[illegible]

TABLE 4.—Total number of days in each month with river readings between values indicated at Cincinnati, 10-year periods, 1861 to 1910, inclusive—Continued.

70 TO 79.9 FEET.

[illegible]

Totals for 50 years and means for each 10-year period.

0 TO 4.9 FEET.

Sums.....	0	0	0	0	0	13	66	182	481	672	313	54	1,781
Means.....	0	0	0	0	0	3	13	36	96	134	63	11	356

5 TO 9.9 FEET.

Sums.....	92	53	17	5	126	389	674	799	646	533	506	309	4,149
Means.....	18	11	3	1	25	78	135	160	129	107	101	62	830

10 TO 19.9 FEET.

Sums.....	580	413	267	400	777	824	675	517	302	269	479	722	6,225
Means.....	116	83	53	80	155	165	135	103	60	54	96	144	1,244

20 TO 29.9 FEET.

Sums.....	464	434	540	619	433	235	113	26	47	59	165	308	3,433
Means.....	93	87	108	124	87	47	23	5	9	12	33	62	687

30 TO 39.9 FEET.

Sums.....	252	259	435	313	153	45	20	15	20	15	37	120	1,685
Means.....	50	52	85	63	31	9	4	3	4	3	7	24	337

40 TO 49.9 FEET.

Sums.....	128	154	209	128	56	5	2	6	4	2	0	37	731
Means.....	26	31	42	26	11	1	0	1	1	0	0	7	146

50 TO 59.9 FEET.

Sums.....	28	76	76	36	5	0	0	5	0	0	0	0	226
Means.....	6	15	15	7	1	0	0	1	0	0	0	0	45

60 TO 69.9 FEET.

Sums.....	6	20	6	0	0	0	0	0	0	0	0	32
Means.....	1	4	1	0	0	0	0	0	0	0	0	6

70 TO 79.9 FEET.

[illegible]

TABLE No. 5.

This table shows the number of days the river at Cincinnati was between each 5 or 10 feet for each month and the year for the two 25-year periods, 1861 to 1885 and 1886 to 1910, all inclusive.

It will be seen that there was very little difference between the total number of flood days of the two periods during the months of January and February, while during the months of March and April the greater number occurred in the second period. It will also be seen that the low-water days were in excess in the first period during the months from June to September, inclusive, while during the second period the low-water days were in excess in November and December.

Flood conditions are not the products of precipitation extending over any considerable period of time, but are, as a rule, the results of abnormal precipitation within a comparatively short time, and there is therefore no direct relation between the average annual precipitation and the number of flood days and the intensity of flood conditions. On the other hand, low-water periods are usually the results of prolonged periods of deficient precipitation, and the relation between the two is therefore quite clearly marked.

TABLE 5.—Total number of days in each month with river readings between values indicated at Cincinnati, 25-year periods, 1861 to 1910, inclusive.

0.0 TO 4.9 FEET.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861-1885.....	0	0	0	0	0	8	39	93	271	335	120	13	879
1886-1910.....	0	0	0	0	0	5	27	89	210	337	193	41	902

5 TO 9.9 FEET.

1861-1885.....	45	28	10	5	57	261	397	408	275	280	242	125	2,133
1886-1910.....	47	25	7	0	69	128	277	391	371	253	264	184	2,016

10 TO 19.9 FEET.

1861-1885.....	275	203	128	181	403	385	289	259	152	125	301	389	3,090
1886-1910.....	305	210	139	219	374	439	386	258	150	144	178	333	3,135

20 TO 29.9 FEET.

1861-1885.....	234	228	300	317	215	81	36	4	33	26	81	137	1,692
1886-1910.....	230	206	240	302	218	144	77	22	14	33	84	171	1,741

30 TO 39.9 FEET.

1861-1885.....	138	120	239	171	79	16	14	2	15	7	6	83	890
1886-1910.....	114	139	196	141	74	29	6	13	5	8	31	37	793

40 TO 49.9 FEET.

1861-1885.....	65	70	81	70	19	0	0	4	4	2	0	28	343
1886-1910.....	63	84	128	58	37	5	2	2	0	0	0	9	388

TABLE 5.—Total number of days in each month with river readings between values indicated at Cincinnati, 25-year periods, 1861 to 1910, inclusive—Continued.

50 TO 59.9 FEET.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861-1885.....	45	37	17	6	2	0	0	5	0	0	0	0	85
1886-1910.....	10	39	59	30	3	0	0	0	0	0	0	0	141

60 TO 69.9 FEET.

1861-1885.....	0	18	0	0	0	0	0	0	0	0	0	0	18
1886-1910.....	6	2	6	0	0	0	0	0	0	0	0	0	14

70 TO 79.9 FEET.

1861-1885.....	0	2	0	0	0	0	0	0	0	0	0	0	2
1886-1910.....	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE No. 6.

In this table is given the average precipitation and the average number of days the river at Cincinnati was above 50 feet, below 5 feet, and below 10 feet for each month and the year for each 10-year and each 25-year period.

TABLE 6.—Average precipitation in the Ohio watershed above Cincinnati, and days with the river above 50 feet, below 5 feet, and below 10 feet at Cincinnati, 1861-1910, inclusive.

1861 TO 1870, INCLUSIVE.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Rainfall (inches).....	3.7	2.7	4.0	3.4	3.8	3.6	3.8	3.6	4.1	2.6	2.8	3.0	41.1
Days with river above 50 feet.....	12	7	17	6	2	0	0	0	0	0	0	0	44
Days with river below 5 feet.....	0	0	0	0	0	8	18	41	88	93	30	8	286
Days with river below 10 feet.....	6	10	0	0	9	89	197	212	185	207	151	56	1,122

1871 TO 1880, INCLUSIVE.

Rainfall (inches).....	3.1	2.6	3.5	3.1	2.7	3.9	5.1	3.6	2.7	2.2	2.9	3.2	38.6
Days with river above 50 feet.....	6	4	0	0	0	0	0	5	0	0	0	0	15
Days with river below 5 feet.....	0	0	0	0	0	0	18	29	100	177	66	1	391
Days with river below 10 feet.....	34	14	6	4	46	160	163	196	259	284	145	64	1,376

1881 TO 1890, INCLUSIVE.

Rainfall (inches).....	4.1	4.3	3.4	3.1	4.3	4.0	3.6	3.6	3.2	2.9	3.2	3.0	42.7
Days with river above 50 feet.....	0	59	15	12	0	0	0	0	0	0	0	0	86
Days with river below 5 feet.....	0	0	0	0	0	0	11	42	124	113	65	8	363
Days with river below 10 feet.....	9	7	4	1	10	50	143	189	192	221	113	49	983

1891 TO 1900, INCLUSIVE.

Rainfall (inches).....	3.3	3.4	4.0	3.0	3.6	3.7	4.2	3.1	2.4	1.9	3.5	2.6	38.7
Days with river above 50 feet.....	5	22	16	5	2	0	0	0	0	0	0	0	50
Days with river below 5 feet.....	0	0	0	0	0	5	19	53	96	193	68	1	435
Days with river below 10 feet.....	29	0	0	0	38	77	173	203	277	255	202	78	1,332

TABLE 6.—Average precipitation in the Ohio watershed above Cincinnati, and days with the river above 50 feet, below 5 feet, and below 10 feet at Cincinnati, 1861-1910, inclusive—Continued.

1901 TO 1910, INCLUSIVE.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Rainfall (inches).....	2.8	2.9	4.0	3.2	3.7	4.3	3.7	2.9	2.4	2.2	1.8	3.1	37.0
Days with river above 50 feet.....	11	6	34	13	1	0	0	0	0	0	0	0	65
Days with river below 5 feet.....	0	0	0	0	0	0	0	17	73	96	84	36	306
Days with river below 10 feet.....	14	22	7	0	23	26	64	181	214	238	208	116	1,113

1861 TO 1885, INCLUSIVE.

	3.5	3.1	3.7	3.2	3.5	3.9	4.2	3.5	3.3	2.6	2.8	3.2	40.5
Rainfall (inches).....	3.5	3.1	3.7	3.2	3.5	3.9	4.2	3.5	3.3	2.6	2.8	3.2	40.5
Days with river above 50 feet.....	18	57	17	6	2	0	0	5	0	0	0	0	106
Days with river below 5 feet.....	0	0	0	0	0	8	39	93	271	335	120	13	879
Days with river below 10 feet.....	45	28	10	5	57	269	436	501	546	615	362	138	3,012

1886 TO 1910, INCLUSIVE.

	3.3	3.3	3.9	3.1	3.8	4.0	4.0	3.2	2.6	2.1	2.9	2.8	38.8
Rainfall (inches).....	3.3	3.3	3.9	3.1	3.8	4.0	4.0	3.2	2.6	2.1	2.9	2.8	38.8
Days with river above 50 feet.....	16	41	65	30	3	0	0	0	0	0	0	0	155
Days with river below 5 feet.....	0	0	0	0	0	5	27	89	210	337	193	41	902
Days with river below 10 feet.....	47	25	7	0	69	133	306	490	581	590	457	215	2,910

TABLE No. 7.

This table is supplementary to Table 6, and gives the departures from the normals for the same data as are shown in Table 6. In these tables we begin to observe the effect of precipitation upon river stages.

TABLE 7.—Departures of precipitation and river-stage days from normals at Cincinnati for days above 50 feet, below 5 feet, and below 10 feet, 1861-1910.

1861 TO 1870, INCLUSIVE.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Precipitation (inches).....	+0.3	-0.5	+0.2	+0.2	+0.2	-0.3	-0.3	+0.3	+1.1	+0.2	0	0	+1.5
Days above 50 feet.....	+ 5	- 13	+ 1	- 2	+ 1	.....	.....	- 1	.....	.....	.....	.....	- 8
Days below 5 feet.....	.....	.....	.....	.....	.....	+ 5	+ 5	+ 5	- 8	- 39	- 33	- 3	- 70
Days below 10 feet.....	- 12	- 1	- 3	- 1	- 17	+ 9	+ 48	+ 16	- 45	- 34	- 13	- 17	- 65

1871 TO 1880, INCLUSIVE.

	-0.3	-0.6	-0.3	-0.1	-0.9	0	+1.0	+0.3	-0.3	-0.2	+0.1	+0.2	-1.3
Precipitation (inches).....	-0.3	-0.6	-0.3	-0.1	-0.9	0	+1.0	+0.3	-0.3	-0.2	+0.1	+0.2	-1.3
Days above 50 feet.....	- 1	- 16	- 16	- 8	- 1	.....	.....	0	.....	.....	.....	.....	- 37
Days below 5 feet.....	.....	.....	.....	.....	.....	- 3	+ 5	- 7	+ 4	+ 43	+ 3	- 10	+ 35
Days below 10 feet.....	+ 16	+ 3	+ 3	+ 3	+ 21	+ 80	+ 14	0	+ 34	+ 43	- 19	- 9	+ 188

1881 TO 1890, INCLUSIVE.

	+0.7	+1.1	-0.4	-0.1	+0.7	+0.1	-0.5	+0.3	+0.2	+0.5	+0.4	0	+3.0
Precipitation (inches).....	+0.7	+1.1	-0.4	-0.1	+0.7	+0.1	-0.5	+0.3	+0.2	+0.5	+0.4	0	+3.0
Days above 50 feet.....	- 7	+ 39	- 1	+ 4	- 1	.....	.....	- 1	.....	.....	.....	.....	+ 34
Days below 5 feet.....	.....	.....	.....	.....	.....	- 3	- 4	+ 6	+ 28	- 21	+ 2	- 3	+ 7
Days below 10 feet.....	- 9	- 4	+ 1	0	- 15	- 30	- 5	- 7	- 33	- 20	- 54	+ 24	- 196

TABLE 7.—Departures of precipitation and river-stage days from normals at Cincinnati for days above 50 feet, below 5 feet, and below 10 feet, 1861–1910, inclusive—Continued.

1891 TO 1900, INCLUSIVE.													
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Precipitation (inches).....	-0.1	+0.2	+0.2	-0.2	0	-0.2	+0.1	-0.2	-0.6	-0.5	+0.7	-0.4	-1.0
Days above 50 feet.....	- 2	+ 2	0	- 3	+ 1	-	-	- 1	-	-	-	-	- 2
Days below 5 feet.....	-	-	-	-	-	+ 2	+ 6	+ 17	0	+ 59	+ 5	- 10	+ 79
Days below 10 feet.....	+ 11	- 11	- 3	- 1	+ 13	- 3	+ 24	+ 7	+ 52	+ 14	+ 38	+ 5	+ 145
1901 TO 1910, INCLUSIVE.													
Precipitation (inches).....	-0.6	-0.3	+0.2	0	+0.1	+0.4	-0.4	-0.4	-0.6	-0.2	-1.0	+0.1	-2.7
Days above 50 feet.....	+ 4	- 14	+ 18	+ 5	0	-	-	- 1	-	-	-	-	+ 13
Days below 5 feet.....	-	-	-	-	-	- 3	- 13	- 19	- 23	- 38	+ 21	+ 25	- 50
Days below 10 feet.....	- 4	+ 11	+ 4	- 1	- 2	- 54	- 85	- 15	- 11	- 3	+ 44	+ 43	- 74
1861 TO 1885, INCLUSIVE.													
Precipitation (inches).....	+0.1	-0.1	-0.1	0	-0.1	0	+0.1	+0.2	+0.3	+0.2	0	+0.2	+0.8
Days above 50 feet.....	+ 1	+ 8	- 24	- 12	0	-	-	+ 3	-	-	-	-	- 25
Days below 5 feet.....	-	-	-	-	-	+ 2	+ 6	+ 2	+ 31	- 1	- 36	- 14	- 11
Days below 10 feet.....	- 1	+ 2	+ 2	+ 3	- 6	+ 68	+ 67	+ 11	- 18	+ 13	- 48	- 44	+ 49
1886 TO 1910, INCLUSIVE.													
Precipitation (inches).....	-0.1	+0.1	+0.1	-0.1	+0.2	+0.1	-0.1	-0.1	-0.4	-0.3	+0.1	-0.2	-0.8
Days above 50 feet.....	- 1	- 8	+ 24	+ 12	+ 1	-	-	- 2	-	-	-	-	+ 25
Days below 5 feet.....	+0.7	+1.1	-0.4	-0.1	+0.7	+0.1	-0.5	+0.3	+0.2	+0.5	+0.4	0	+3.0
Days below 10 feet.....	+ 1	- 1	- 1	- 2	+ 6	- 68	- 68	- 10	+ 17	- 12	+ 47	+ 43	- 48

TABLE No. 8.

In this table is shown the comparison between the departures of the precipitation from the normals for each month of each 10 years, and the number of days the river stages were above or below the normal number of days for the different 5 or 10 foot heights for the same 10-year periods.

TABLE 8.—Departures of precipitation and river-stage days from normals, Ohio Watershed above Cincinnati, 1861 to 1910, inclusive.

PRECIPITATION.													
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1861-1870.....	+0.3	-0.5	+0.2	+0.2	+0.2	-0.3	-0.3	+0.3	+1.1	+0.2	0	0	+1.5
1871-1880.....	-0.3	-0.6	-0.3	-0.1	-0.9	0	+1.0	+0.3	-0.3	-0.2	+0.1	+0.2	-1.3
1881-1890.....	+0.7	+1.1	-0.4	-0.1	+0.7	+0.1	-0.5	+0.3	+0.2	+0.5	+0.4	0	+3.0
1891-1900.....	-0.1	+0.2	+0.2	-0.2	0	-0.2	+0.1	-0.2	-0.6	-0.5	+0.7	-0.4	-1.0
1901-1910.....	-0.6	-0.3	+0.2	0	+0.1	+0.4	-0.4	-0.4	-0.6	-0.2	-1.0	+0.1	-2.7
DAYS WITH RIVER 0 TO 4.9 FEET, INCLUSIVE.													
1861-1870.....						+ 5	+ 5	+ 5	- 8	-39	-33	- 3	-70
1871-1880.....						- 3	+ 5	- 7	+ 4	+43	+ 3	-10	+35
1881-1890.....						- 3	- 4	+ 6	+28	-21	+ 2	- 3	+ 7
1891-1900.....						+ 2	+ 6	+17	0	+59	+ 5	-10	+79
1901-1910.....						- 3	-13	-19	-23	-38	+21	+25	-50

TABLE 8.—Departures of precipitation and river-stage days from normals, Ohio watershed above Cincinnati, 1861 to 1910, inclusive—Continued.

DAYS WITH RIVER 5 TO 9.9 FEET, INCLUSIVE.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	An- nual.
1861-1870.....	-12	-1	-3	-1	-16	+3	+44	+11	-32	+7	+20	-14	+6
1871-1880.....	+16	+3	+3	+3	+21	+82	+10	+6	+30	0	-22	+1	+154
1881-1890.....	-9	+4	+1	0	-15	-28	-1	-13	-61	+1	-53	-21	-203
1891-1900.....	+11	-11	-3	-1	+13	-6	+19	-10	+52	-45	+33	+15	+6
1901-1910.....	-4	+11	+4	-1	-2	-52	-71	+4	+12	+25	+13	+18	-23

DAYS WITH RIVER 10 TO 19.9 FEET, INCLUSIVE.

1861-1870.....	+ 8	+ 2	-19	-51	- 8	+ 2	-41	- 5	+22	+18	- 1	- 4	-76
1871-1880.....	-14	+10	+19	+36	+ 7	-30	- 8	- 3	-38	-32	+37	+ 3	-13
1881-1890.....	-27	-34	+26	+15	+17	- 4	- 2	+ 9	+29	+ 4	+ 4	+27	+64
1891-1900.....	+12	- 2	- 7	+ 9	- 6	+20	-20	-19	-37	- 8	-16	+17	-55
1901-1910.....	+21	+21	-19	- 9	- 8	+10	+69	+20	+26	+17	-25	-41	+82

DAYS WITH RIVER 20 TO 29.9 FEET, INCLUSIVE.

1861-1870.....	- 3	+12	+ 8	+28	+12	- 3	- 4	- 5	+12	+10	+20	+ 9	+98
1871-1880.....	+ 3	+19	+14	-20	-13	-42	-17	- 2	+ 3	- 8	-16	- 8	-84
1881-1890.....	+26	-20	- 3	-23	- 9	+19	+ 7	+ 1	+ 5	+11	+30	+ 3	+50
1891-1900.....	-19	- 5	+ 3	+ 4	+ 3	-13	- 7	+ 6	- 9	- 3	-18	+ 2	-53
1901-1910.....	- 7	- 7	-22	+ 9	+ 5	+29	+19	+ 1	- 9	-11	-16	- 8	-14

DAYS WITH RIVER 30 TO 39.9 FEET, INCLUSIVE.

1861-1870.....	+14	+7	+12	+7	+14	-9	-4	-3	+4	+4	-6	+12	+52
1871-1880.....	0	-9	+7	-2	-10	-9	+10	-1	+3	-3	-2	+8	-8
1881-1890.....	+6	+7	-18	+6	+8	+14	-2	0	+1	+5	+17	-7	+23
1891-1900.....	-8	+15	+17	-8	-9	-5	0	+7	-4	-3	-4	-18	-20
1901-1910.....	-10	-7	-18	-5	-5	+9	-4	-3	-4	-3	-3	+5	-48

DAYS WITH RIVER 40 TO 49.9 FEET, INCLUSIVE.

1861-1870.....	-12	-10	+ 2	+17	- 3	- 1	0	- 1	+ 3	+ 2	0	- 3
1871-1880.....	- 3	- 8	-26	-11	- 4	- 1	0	+ 3	- 1	0	+ 6	-45
1881-1890.....	+ 9	+24	- 4	- 4	0	- 1	0	- 1	- 1	0	+ 1	+25
1891-1900.....	+ 6	- 1	-11	- 3	- 2	- 1	+ 2	+ 1	- 1	0	- 6	-16
1901-1910.....	- 4	- 6	+38	- 1	+10	+ 4	0	- 1	- 1	0	+ 1	+40

DAYS WITH RIVER 50 TO 59.9 FEET, INCLUSIVE.

1861-1870.....	+ 6	- 8	+ 2	- 1	+ 1							- 1
1871-1880.....	0	-11	-15	- 7	- 1							-30
1881-1890.....	- 6	+24	0	+ 5	- 1							+21
1891-1900.....	- 1	+ 5	- 1	- 2	+ 1							+ 1
1901-1910.....	- 1	- 9	+15	+ 6	0							+10

DAYS WITH RIVER 60 TO 60.9 FEET, INCLUSIVE.

1861-1870.....	- 1	- 4	- 1							- 6
1871-1880.....	- 1	- 4	- 1							- 6
1881-1890.....	- 1	+14	- 1							+12
1891-1900.....	- 1	+ 1	- 2							- 2
1901-1910.....	+ 5	- 4	+ 3							+ 4

DAYS WITH RIVER 70 TO 79.9 FEET, INCLUSIVE.

[illegible]

TABLE No. 9.

This table shows the number of days the Ohio River at Cincinnati was above the flood stage of 50 feet for each month during the entire 50 years, together with the totals for each year and for each month.

TABLE 9.—Total number of days with river above 50 feet at Cincinnati, Ohio, 1861 to 1910, inclusive.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861.	0	0	0	0	0	0	0	0	0	0	0	0	0
1862.	6	0	0	6	0	0	0	0	0	0	0	0	12
1863.	0	0	0	0	0	0	0	0	0	0	0	0	0
1864.	0	0	0	0	0	0	0	0	0	0	0	0	0
1865.	0	0	5	0	2	0	0	0	0	0	0	0	7
1866.	0	0	0	0	0	0	0	0	0	0	0	0	0
1867.	0	7	12	0	0	0	0	0	0	0	0	0	19
1868.	0	0	0	0	0	0	0	0	0	0	0	0	0
1869.	0	0	0	0	0	0	0	0	0	0	0	0	0
1870.	6	0	0	0	0	0	0	0	0	0	0	0	6
1871.	0	0	0	0	0	0	0	0	0	0	0	0	0
1872.	0	0	0	0	0	0	0	0	0	0	0	0	0
1873.	0	0	0	0	0	0	0	0	0	0	0	0	0
1874.	0	0	0	0	0	0	0	0	0	0	0	0	0
1875.	0	0	0	0	0	0	0	5	0	0	0	0	5
1876.	1	0	0	0	0	0	0	0	0	0	0	0	1
1877.	5	0	0	0	0	0	0	0	0	0	0	0	5
1878.	0	0	0	0	0	0	0	0	0	0	0	0	0
1879.	0	0	0	0	0	0	0	0	0	0	0	0	0
1880.	0	4	0	0	0	0	0	0	0	0	0	0	4
1881.	0	2	0	0	0	0	0	0	0	0	0	0	2
1882.	0	9	0	0	0	0	0	0	0	0	0	0	9
1883.	0	16	0	0	0	0	0	0	0	0	0	0	16
1884.	0	19	0	0	0	0	0	0	0	0	0	0	19
1885.	0	0	0	0	0	0	0	0	0	0	0	0	0
1886.	0	0	0	12	0	0	0	0	0	0	0	0	12
1887.	0	10	3	0	0	0	0	0	0	0	0	0	13
1888.	0	0	0	0	0	0	0	0	0	0	0	0	0
1889.	0	0	0	0	0	0	0	0	0	0	0	0	0
1890.	0	3	12	0	0	0	0	0	0	0	0	0	15
1891.	0	8	0	0	0	0	0	0	0	0	0	0	8
1892.	0	0	0	0	0	0	0	0	0	0	0	0	0
1893.	0	8	0	0	2	0	0	0	0	0	0	0	10
1894.	0	0	0	0	0	0	0	0	0	0	0	0	0
1895.	0	0	0	0	0	0	0	0	0	0	0	0	0
1896.	0	0	0	0	0	0	0	0	0	0	0	0	0
1897.	0	6	2	0	0	0	0	0	0	0	0	0	8
1898.	5	0	7	3	0	0	0	0	0	0	0	0	15
1899.	0	0	7	2	0	0	0	0	0	0	0	0	9
1900.	0	0	0	0	0	0	0	0	0	0	0	0	0
1901.	0	0	0	8	1	0	0	0	0	0	0	0	9
1902.	0	0	4	0	0	0	0	0	0	0	0	0	4
1903.	0	0	8	0	0	0	0	0	0	0	0	0	8
1904.	0	0	0	0	0	0	0	0	0	0	0	0	0
1905.	0	0	0	0	0	0	0	0	0	0	0	0	0
1906.	0	0	0	1	0	0	0	0	0	0	0	0	1
1907.	11	0	11	0	0	0	0	0	0	0	0	0	22
1908.	0	2	6	4	0	0	0	0	0	0	0	0	12
1909.	0	4	2	0	0	0	0	0	0	0	0	0	6
1910.	0	0	3	0	0	0	0	0	0	0	0	0	3
Sums.	34	98	82	36	5	0	0	5	0	0	0	0	260

TABLE No. 10.

The table shows the number of days the Ohio River at Cincinnati was above the 40-foot stage for each month during the entire 50 years, together with the totals for each year and for each month.

TABLE 10.—Total number of days with river above 40 feet at Cincinnati, Ohio, 1861 to 1910, inclusive.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
1861.....	2	0	0	7	0	0	0	0	0	2	0	0	11
1862.....	10	10	6	15	0	0	0	0	0	0	0	0	41
1863.....	1	1	3	0	0	0	0	0	0	0	0	0	5
1864.....	0	0	0	0	0	0	0	0	0	0	0	5	5
1865.....	0	2	19	8	8	0	0	0	0	0	0	2	37
1866.....	0	0	0	0	0	0	0	0	2	0	0	0	2
1867.....	0	15	19	0	0	0	0	0	0	0	0	0	34
1868.....	3	0	10	2	2	0	0	0	2	0	0	0	19
1869.....	0	0	2	6	0	0	0	0	0	0	0	0	8
1870.....	10	0	2	13	0	0	0	0	0	0	0	0	25
1871.....	0	0	0	0	1	0	0	0	0	0	0	0	1
1872.....	0	0	0	5	0	0	0	0	0	0	0	0	5
1873.....	0	3	0	0	0	0	0	0	0	0	0	4	7
1874.....	6	5	0	6	4	0	0	0	0	0	0	0	21
1875.....	0	0	5	0	0	0	0	9	0	0	0	4	18
1876.....	11	10	1	1	0	0	0	0	0	0	0	0	23
1877.....	9	0	3	0	0	0	0	0	0	0	0	0	12
1878.....	0	0	0	0	0	0	0	0	0	0	0	3	3
1879.....	0	2	0	0	0	0	0	0	0	0	0	2	4
1880.....	3	7	7	3	2	0	0	0	0	0	0	0	22
1881.....	0	9	0	3	0	0	0	0	0	0	0	2	14
1882.....	23	20	6	0	4	0	0	0	0	0	0	0	53
1883.....	0	18	0	9	0	0	0	0	0	0	0	6	33
1884.....	0	25	15	0	0	0	0	0	0	9	0	0	40
1885.....	5	0	0	0	0	0	0	0	0	9	0	0	5
1886.....	0	1	1	16	0	0	0	0	0	9	0	0	18
1887.....	3	26	7	5	0	0	0	0	0	9	0	0	43
1888.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1889.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1890.....	6	13	24	1	7	0	0	0	0	0	0	0	51
1891.....	6	26	10	6	0	0	0	0	0	0	0	9	48
1892.....	2	0	0	6	0	0	0	0	0	0	0	0	8
1893.....	0	14	0	1	11	0	0	0	0	9	0	0	26
1894.....	0	0	0	0	0	0	0	0	0	0	0	0	0
1895.....	5	0	0	0	0	0	0	0	0	0	0	0	5
1896.....	0	0	0	6	0	0	2	2	0	9	0	0	10
1897.....	0	12	14	0	0	0	0	0	0	0	0	0	26
1898.....	16	0	10	5	0	0	0	0	0	0	0	0	31
1899.....	8	0	13	4	0	0	0	0	0	0	0	0	25
1900.....	0	0	0	0	0	0	0	0	0	0	0	1	1
1901.....	0	0	0	10	3	2	0	0	0	0	0	0	15
1902.....	2	2	15	3	0	0	0	0	0	0	0	7	29
1903.....	0	14	19	5	0	0	0	0	0	0	0	0	38
1904.....	4	0	14	5	0	0	0	0	0	0	0	0	23
1905.....	0	0	11	0	6	0	0	0	0	9	0	1	18
1906.....	0	0	1	6	0	0	0	0	0	9	0	0	7
1907.....	19	0	15	0	0	3	0	0	0	0	0	0	37
1908.....	0	9	19	9	6	0	0	0	0	0	0	0	43
1909.....	0	5	8	0	7	0	0	0	0	0	0	0	20
1910.....	8	1	12	0	0	0	0	0	0	0	0	0	21
Sums.....	162	252	291	164	61	5	2	11	4	2	0	37	991

TABLE No. 11.

This table shows the number of days the Ohio River at Cincinnati was below the 10-foot stage for each month during the entire 50 years, together with the totals for each year and for each month.

TABLE 11.—Total number of days with river below 10 feet at Cincinnati, Ohio, 1861–1910, inclusive.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
1861	0	0	0	0	0	12	31	11	22	0	0	0	76
1862	0	0	0	0	0	0	8	31	30	31	27	23	150
1863	0	0	0	0	4	30	24	31	30	31	22	6	178
1864	6	7	0	0	0	11	31	21	3	9	2	0	90
1865	0	0	0	0	0	0	9	13	8	26	16	11	82
1866	0	0	0	0	5	30	18	22	7	5	1	0	88
1867	0	0	0	0	0	1	28	31	30	31	30	15	166
1868	0	3	0	0	0	3	31	21	10	20	5	0	93
1869	0	0	0	0	0	0	0	22	19	24	23	0	88
1870	0	0	0	0	0	0	2	17	9	26	31	25	111
1871	14	0	0	0	3	27	31	31	30	31	24	25	216
1872	11	9	5	4	8	12	11	23	30	31	17	19	180
1873	0	0	0	0	0	28	6	12	25	24	4	0	94
1874	0	0	0	0	7	30	29	24	30	31	27	3	181
1875	5	4	0	0	6	4	0	1	30	31	6	0	87
1876	0	0	0	0	0	15	8	18	12	17	8	7	85
1877	0	1	1	0	0	10	11	31	30	31	16	0	131
1878	4	0	0	0	0	0	9	22	17	18	26	4	100
1879	0	0	0	0	10	25	31	18	24	31	25	7	171
1880	0	0	0	0	12	5	14	21	30	31	14	3	130
1881	5	0	0	0	2	8	25	31	30	31	6	0	138
1882	0	0	0	0	0	0	2	11	0	21	30	6	70
1883	0	0	0	0	0	0	2	21	30	24	0	0	77
1884	0	0	0	0	0	0	8	18	27	30	31	12	156
1885	0	4	4	1	0	4	29	3	12	17	0	0	74
1886	0	0	0	0	0	0	2	6	14	30	31	17	100
1887	0	0	0	0	3	9	31	31	30	31	30	31	196
1888	4	3	0	0	5	19	12	20	2	11	0	0	76
1889	0	0	0	0	0	0	0	10	28	24	0	0	62
1890	0	0	0	0	0	0	18	21	0	0	0	0	39
1891	0	0	0	0	20	0	3	12	17	31	21	0	104
1892	0	0	0	0	0	0	10	28	30	31	30	18	147
1893	5	0	0	0	0	0	21	31	25	15	18	2	117
1894	0	0	0	0	2	11	31	31	26	31	30	11	173
1895	5	0	0	0	0	29	28	31	30	31	30	23	207
1896	11	0	0	0	10	6	1	0	30	2	1	0	61
1897	1	0	0	0	0	6	6	20	30	31	19	0	113
1898	0	0	0	0	0	9	25	0	29	22	0	0	85
1899	0	0	0	0	0	0	26	24	30	31	30	15	156
1900	7	0	0	0	6	16	22	26	30	30	23	9	169
1901	4	4	7	0	0	0	4	14	12	31	29	0	105
1902	6	8	0	0	4	15	0	18	30	27	27	0	135
1903	0	0	0	0	12	0	2	31	22	27	23	21	138
1904	0	0	0	0	0	4	8	31	30	31	30	30	164
1905	1	7	0	0	0	0	0	3	14	19	0	0	44
1906	0	3	0	0	7	3	17	5	16	0	8	0	59
1907	0	0	0	0	0	0	0	5	1	18	2	0	26
1908	0	0	0	0	0	4	19	24	30	31	30	26	164
1909	1	0	0	0	0	0	9	19	30	30	29	23	141
1910	2	0	0	0	0	0	5	31	29	24	30	16	137
Sums.....	92	53	17	5	126	402	740	981	1,127	1,205	819	363	5,930

TABLE No. 12.

A correlation is here shown between the precipitation for August, September, and October and the number of days that the river was below 10 feet at Cincinnati, during the same months, for each year of the entire 50 years. This is the usual correlation table. In these tables the correlation coefficient "r" is determined by dividing the sum of column 8 by the square root of the product of the sums of

columns 4 and 7. If the correlation coefficient be 1 in this calculation, there is an exact relation between the two factors, and if -1 there is an exact opposite connection. In this case $426.74 \times 26,562$ (the sums of columns 4 and 7, respectively) = 11,335,067.88. The square root of this product is 3,366.76. The sum of column 8 is -2,490.8. This sum divided by 3,366.76 = -0.74. This is a very high negative coefficient and shows plainly that the smaller the amount of rainfall during August, September, and October the greater the number of days with the river below 10 feet.

It is considered safe to assume that there is a well-defined relation in these cases if "r" is six times the probable error. The probable error is obtained by the following formula: $0.674 \frac{1-r^2}{\sqrt{N}}$. In which "r" is

the correlation coefficient and N the number of years under discussion. The probable error here is ± 0.04 , or only one-eighteenth of "r."

The question might properly be raised as to whether the rainfall during July might have a marked influence on the low-water days in August, September, and October, as discussed in this table. But a similar correlation table worked out for the rainfall for July, August, September, and October, and the number of days with the river below 10 feet in August, September, and October, gives a correlation coefficient of -0.73, or very slightly less than with July rainfall omitted.

TABLE 12.—Correlation of precipitation and days with river below 10 feet, in August, September, and October, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.

Years.	Precipitation.			Days.			Product of columns 3 and 6.
	Precipitation.	Departure.	Square of column 3.	Days.	Departure.	Square of column 6.	
1	2	3	4	5	6	7	8
	<i>Inches.</i>	<i>Inches.</i>		<i>Days.</i>	<i>Days.</i>		
1861.....	11.4	+2.7	7.29	33	-33	1,089	- 89.2
1862.....	5.0	-3.7	13.69	92	+26	676	- 96.2
1863.....	8.7	0	0	92	+26	676	- 0
1864.....	12.7	+4.0	16.00	33	-33	1,089	- 132.0
1865.....	10.2	+1.5	2.25	46	-20	400	- 30.0
1866.....	17.2	+8.5	72.25	34	-32	1,024	- 272.0
1867.....	6.6	-2.1	4.41	92	+26	676	- 54.6
1868.....	13.9	+5.2	27.04	51	-15	225	- 73.0
1869.....	8.2	-0.5	.25	65	-1	1	+ 0.5
1870.....	7.4	-1.3	1.69	66	0	0	- 0
1871.....	7.5	-1.2	1.44	92	+26	676	- 31.2
1872.....	7.2	-1.5	2.25	84	+18	324	- 27.0
1873.....	10.6	+1.9	3.61	61	-5	25	- 9.5
1874.....	5.6	-3.1	9.61	85	+19	364	- 58.9
1875.....	7.8	-0.9	.81	62	-4	16	+ 3.6
1876.....	11.5	+2.8	7.84	47	-19	361	- 53.2
1877.....	5.9	-2.8	7.84	92	+26	676	- 72.8
1878.....	10.1	+1.4	1.96	61	-5	25	- 7.0
1879.....	9.7	+1.0	1.00	73	+7	49	+ 7.0
1880.....	9.5	+0.8	.64	82	+16	256	+ 12.8
1881.....	8.8	+0.1	.01	92	+26	676	+ 2.6
1882.....	10.1	+1.4	1.96	32	-34	1,156	- 47.6
1883.....	9.3	+0.6	.36	75	+9	81	+ 5.4
1884.....	6.8	-1.9	3.61	88	+22	284	- 41.8
1885.....	12.0	+3.3	10.89	32	-34	1,156	- 112.2
1886.....	8.1	-0.6	0.36	75	+9	81	- 5.4
1887.....	5.4	-3.3	10.89	92	+26	676	- 85.8
1888.....	14.3	+5.6	31.36	33	-33	1,089	- 124.8
1889.....	7.4	-1.3	1.69	62	-4	16	+ 5.2

TABLE 12.—Correlation of precipitation and days with river below 10 feet in August, September, and October, Ohio River, Cincinnati Ohio, 1861 to 1910, inclusive—Continued.

Years.	Precipitation.			Days.			Product of columns 3 and 6.
	Precipitation.	Departure.	Square of column 3.	Days.	Departure.	Square of column 6.	
1	2	3	4	5	6	7	8
	<i>Inches.</i>	<i>Inches.</i>		<i>Days.</i>	<i>Days.</i>		
1860.....	14.6	+5.9	34.81	21	-45	2,025	- 265.5
1861.....	6.5	-2.2	4.84	60	- 6	36	+ 13.2
1862.....	6.5	-2.2	4.84	89	+23	529	- 50.6
1863.....	8.7	0	0	71	+ 5	25	0
1864.....	7.2	-1.5	2.25	88	+22	484	- 33.0
1865.....	5.1	-3.6	12.96	92	+26	676	- 93.6
1866.....	10.3	+1.6	2.56	32	-34	1,156	- 54.4
1867.....	3.8	-4.9	24.01	81	+15	225	- 73.5
1868.....	10.9	+2.2	4.84	51	-15	225	- 33.0
1869.....	7.3	-1.4	1.96	85	+19	361	- 26.6
1870.....	6.8	-1.9	3.61	86	+20	400	- 38.0
1871.....	6.4	-2.3	5.29	57	- 9	81	+ 20.7
1872.....	7.5	-1.2	1.44	75	+ 9	81	- 10.8
1873.....	5.5	-3.2	10.24	80	+14	196	- 44.8
1874.....	4.7	-4.0	16.00	92	+26	676	- 104.0
1875.....	12.5	+3.8	14.44	36	-30	900	- 114.0
1876.....	10.9	+2.2	4.84	21	-45	2,025	- 99.0
1877.....	7.7	-1.0	10.00	24	-42	1,764	+ 42.0
1878.....	4.3	-4.4	19.36	85	+19	361	- 83.6
1879.....	7.1	-1.6	2.56	79	+13	169	- 20.8
1880.....	10.4	+1.7	2.89	84	+18	324	+ 30.6
Sums.....			426.74			26,562	-2,490.8
Means.....	8.7			66			

The correlation coefficient is -0.74. The probable error is ± 0.04 .

TABLE 13.

In Table 13 the correlation coefficient is determined for the precipitation over the Ohio watershed above Cincinnati, and the number of days that the river was above 40 feet at Cincinnati, during the months of February and March, for the 50 years. The effect of the precipitation upon the flood conditions is more remarkable, if possible, than upon the low-water days as indicated in Table 12, because the correlation coefficient is 0.80 in Table 13. This is 27 times the probable error. This table alone should be very conclusive evidence that the high-water conditions in the Ohio Valley, during the months when there are the greatest number of high-water days, are controlled by the precipitation and nothing else.

By obtaining the correlation coefficient for the different 25-year periods from this table the fact that the cutting off of the forests does not make increased flood conditions is plainly established. The correlation coefficient for the 25 years from 1861 to 1885, inclusive, is 0.805, and for the 25 years from 1886 to 1910, inclusive, is 0.804, a difference much less than the probable error. This means that the tendency to cause the water to rise above 40 feet by the same precipitation has been no greater during the last 25 years than during the preceding 25 years, or at least by a value too small to be calculated by the most approved method of correlation.

TABLE 13.—*Precipitation and days with river above 40 feet in February and March, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.*

Years.	Precipitation.			Days.			Product of columns 3 and 6.
	Precipitation.	Departure.	Square of column 3.	Days.	Departure.	Square of column 6.	
1	2	3	4	5	6	7	8
	Inches.	Inches.		Days.	Days.		
1861.....	4.3	-2.7	7.29	0	-11	121	+ 29.7
1862.....	7.7	+0.1	.49	16	+ 5	25	+ 0.5
1863.....	7.1	+0.1	.01	4	- 7	49	- 0.7
1864.....	4.0	-3.0	9.00	0	-11	121	+ 33.0
1865.....	7.4	+0.4	.16	21	+10	100	+ 4.0
1866.....	6.2	-0.8	.64	0	-11	121	+ 8.8
1867.....	10.0	+3.0	9.00	34	+23	529	+ 66.0
1868.....	6.5	-0.5	.25	10	- 1	1	+ 0.5
1869.....	7.1	+0.1	.01	2	- 9	81	- 0.9
1870.....	7.3	+0.3	.09	2	- 9	81	- 2.7
1871.....	5.3	-1.7	2.89	0	-11	121	+ 13.7
1872.....	3.4	-3.6	12.96	0	-11	121	+ 36.6
1873.....	6.7	-0.3	.09	3	- 8	64	+ 2.4
1874.....	7.6	+0.6	.36	5	- 6	36	+ 3.6
1875.....	5.8	-1.2	1.44	5	- 6	36	+ 7.2
1876.....	6.0	-0.7	.49	11	0	0	0.0
1877.....	4.7	-2.3	5.92	3	- 8	64	+ 8.0
1878.....	7.1	+0.1	.01	2	- 9	81	- 28.3
1879.....	8.0	+1.0	1.00	14	+ 5	25	+ 0.9
1880.....	7.2	+0.2	.04	9	- 2	4	+ 0.4
1881.....	10.1	+3.1	9.61	26	+15	225	+ 46.5
1882.....	10.2	+3.2	10.24	18	+ 7	49	+ 22.4
1883.....	10.2	+3.2	10.24	40	+29	841	+ 92.8
1884.....	3.3	-3.7	13.69	0	-11	121	+ 40.7
1885.....	5.1	-1.9	3.61	2	- 9	81	+ 17.1
1886.....	9.4	+2.4	5.76	35	+24	576	+ 57.6
1887.....	6.1	-0.9	.81	0	-11	121	+ 9.9
1888.....	2.9	-4.1	16.81	0	-11	121	+ 45.1
1889.....	12.3	+5.3	28.09	37	+26	676	+ 137.8
1890.....	10.0	+3.0	9.00	36	+25	625	+ 75.0
1891.....	6.1	-0.9	.81	0	-11	121	+ 9.9
1892.....	7.4	+0.4	.16	14	+ 3	9	+ 1.2
1893.....	5.9	-1.1	1.21	0	-11	121	+ 12.1
1894.....	3.1	-3.9	15.21	0	-11	121	+ 42.9
1895.....	6.7	-0.3	.09	0	-11	121	+ 3.3
1896.....	11.3	+4.3	18.49	26	+15	225	+ 64.5
1897.....	9.3	+2.3	5.29	10	- 1	1	+ 2.3
1898.....	8.4	+1.4	1.96	13	+ 2	4	+ 2.8
1899.....	5.4	-1.6	2.56	0	-11	121	+ 17.6
1900.....	3.7	-3.3	10.89	0	-11	121	+ 36.3
1901.....	4.2	-2.8	7.84	17	+ 6	36	+ 16.8
1902.....	9.9	+2.9	8.41	33	+22	484	+ 63.8
1903.....	8.0	+1.0	1.00	14	+ 3	9	+ 3.0
1904.....	5.2	-1.8	3.21	11	0	0	0.0
1905.....	6.9	-0.1	.01	1	-10	100	+ 1.0
1906.....	7.0	0	0	15	+ 4	16	0.0
1907.....	10.6	+3.6	12.96	28	+17	289	+ 61.2
1908.....	8.9	+1.9	3.61	13	+ 2	4	+ 3.8
1909.....	7.3	+0.3	.09	13	+ 2	4	+ 0.6
1910.....							
Sums.....			254.80			7,245	+1,092.3
Means.....	7.0			11			

The correlation coefficient is 0.80. The probable error is ± 0.03 .

TABLE 14.

In this table the same calculation is made for the relation between the precipitation in February and March and the number of days above 50 feet, or flood stage. One would not expect this correlation coefficient to be so high as in Table 13, even if the relation is actually closer, because of the great number of years when the river did not

rise above 50 feet during these two months. And yet in this case "r" equals 0.74; high enough to make the relation well marked. The determination of the correlation coefficient in this table for each of the 25-year periods shows that the tendency to produce flood days with the same rainfall is slightly less during the last 25 years than during the preceding, although by a value too small to be considered, being about 0.3 per cent.

TABLE 14.—*Precipitation and days with river above 50 feet in February and March, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.*

Years.	Precipitation.			Days.			Product of columns 3 and 6.
	Precipitation.	Departure.	Square of column 3.	Days.	Departure.	Square of column 6.	
1	2	3	4	5	6	7	8
	<i>Inches.</i>	<i>Inches.</i>		<i>Days.</i>	<i>Days.</i>		
1861.....	4.3	-2.7	7.29	0	-4	16	+ 10.8
1862.....	7.7	+0.7	.49	0	-4	16	- 2.8
1863.....	7.1	+0.1	.01	0	-4	16	- 0.4
1864.....	4.0	-3.0	9.00	0	-4	16	+ 12.0
1865.....	7.4	+0.4	.16	5	+1	1	+ 0.4
1866.....	6.2	-0.8	.64	0	-4	16	+ 3.2
1867.....	10.0	+3.0	9.00	19	+15	225	+ 45.0
1868.....	6.5	-0.5	.25	0	-4	16	+ 2.0
1869.....	7.1	+0.1	.01	0	-4	16	- 0.4
1870.....	7.3	+0.3	.09	0	-4	16	- 1.2
1871.....	5.3	-1.7	2.89	0	-4	16	+ 6.8
1872.....	3.4	-3.6	12.96	0	-4	16	+ 14.4
1873.....	6.7	-0.3	.09	0	-4	16	+ 1.2
1874.....	7.6	+0.6	.36	0	-4	16	- 2.4
1875.....	5.8	-1.2	1.44	0	-4	16	+ 4.8
1876.....	6.3	-0.7	.49	0	-4	16	+ 2.8
1877.....	6.0	-1.0	1.00	0	-4	16	+ 4.0
1878.....	4.7	-2.3	5.92	0	-4	16	+ 9.2
1879.....	7.1	+0.1	.01	0	-4	16	- 0.4
1880.....	8.0	+1.0	1.00	4	0	0	0
1881.....	7.2	+0.2	.04	2	-2	4	- 0.4
1882.....	10.1	+3.1	9.61	9	+5	25	+ 15.5
1883.....	10.2	+3.2	10.24	16	+12	144	+ 38.4
1884.....	10.2	+3.2	10.24	19	+15	225	+ 48.0
1885.....	3.3	-3.7	13.69	0	-4	16	+ 14.8
1886.....	5.1	-1.9	3.61	0	-4	16	+ 7.6
1887.....	9.4	+2.4	5.76	13	+9	81	+ 21.6
1888.....	6.1	-0.9	.81	0	-4	16	+ 3.6
1889.....	2.9	-4.1	16.81	0	-4	16	+ 16.4
1890.....	12.3	+5.3	28.09	15	+11	121	+ 58.3
1891.....	10.0	+3.0	9.00	8	+4	16	+ 12.0
1892.....	6.1	-0.9	.81	0	-4	16	+ 3.6
1893.....	7.4	+0.4	.16	8	+4	16	+ 1.6
1894.....	5.9	-1.1	1.21	0	-4	16	+ 4.4
1895.....	3.1	-3.9	15.21	0	-4	16	+ 15.6
1896.....	6.7	-0.3	.09	0	-4	16	+ 1.2
1897.....	11.3	+4.3	18.49	8	+4	16	+ 17.2
1898.....	9.3	+2.3	5.29	7	+3	9	+ 6.9
1899.....	8.4	+1.4	1.96	7	+3	9	+ 4.2
1900.....	5.4	-1.6	2.56	0	-4	16	+ 6.4
1901.....	3.7	-3.3	10.89	0	-4	16	+ 13.2
1902.....	4.2	-2.8	7.84	4	0	0	0
1903.....	9.9	+2.9	8.41	8	+4	16	+ 11.6
1904.....	8.0	+1.0	1.00	0	-4	16	- 4.0
1905.....	5.2	-1.8	3.21	0	-4	16	+ 7.3
1906.....	6.9	-0.1	.01	0	-4	16	+ 0.4
1907.....	7.0	0	0	11	+7	49	0
1908.....	10.6	+3.6	12.96	8	+4	16	+ 14.4
1909.....	8.9	+1.9	3.61	6	+2	4	+ 3.8
1910.....	7.3	+0.3	.09	3	-1	1	- 0.3
Sum.....			254.80			1,458	+452.3
Mean.....	7.0			4			

The correlation coefficient is 0.74.

TABLE 15.

In this table the years, precipitation, and river stages are grouped for each difference in precipitation amounting to 1 inch for February and March. This table shows several important facts, among them being:

(1) In only one year has the river reached the flood stage during these months when the precipitation was less than the normal, 7 inches.

(2) The most marked increase in flood days comes with the increase of the precipitation from between 9 and 10 inches to between 10 and 11 inches.

(3) The average rate of increase in number of flood days with each increase of 1 inch in the precipitation is 2.5; this calculation is made for years when the precipitation was above 7 inches.

TABLE 15.—*Precipitation and days with river above 50 feet in February and March, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.*

Precipitation between—	Years.	Precipitation.	Days.	Change.
2.9 and 3.9 inches	1872	3.4	0	.....
	1885	3.3	0	.....
	1889	2.9	0	.....
	1895	3.1	0	.....
	1901	3.7	0	.....
4 and 4.9 inches	1861	4.3	0	.....
	1864	4.0	0	.....
	1878	4.7	0	.....
	1902	4.2	4	.....
5 and 5.9 inches	1871	5.3	0	.....
	1875	5.8	0	.....
	1886	5.1	0	.....
	1894	5.9	0	.....
	1900	5.4	0	.....
	1905	5.2	0	.....
6 and 6.9 inches	1866	6.2	0	.....
	1868	6.5	0	.....
	1873	6.7	0	.....
	1876	6.3	0	.....
	1877	6.0	0	.....
	1888	6.1	0	.....
	1892	6.1	0	.....
	1896	6.7	0	.....
	1906	6.9	0	.....
7 and 7.9 inches	1862	7.7	0	.....
	1863	7.1	0	.....
	1865	7.4	5	.....
	1869	7.1	0	.....
	1870	7.3	0	.....
	1874	7.6	0	.....
	1879	7.1	0	.....
	1881	7.2	2	.....
	1893	7.4	8	.....
	1907	7.0	11	.....
	1910	7.3	3	.....
Mean			2	.....
8 and 8.9 inches	1880	8.0	4	.....
	1899	8.4	7	.....
	1904	8.0	0	.....
	1906	8.9	9	.....
Mean			5	3

TABLE 15.—*Precipitation and days with river above 50 feet in February and March, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive—Continued.*

Precipitation between—	Years.	Precipitation.	Days.	Change.
9 and 9.9 inches	1887	9.4	13	.....
	1886	9.3	7	.....
	1903	9.9	8	.....
Mean			9	4
10 and 10.9 inches	1867	10.0	19	.....
	1882	10.1	9	.....
	1883	10.2	16	.....
	1884	10.2	19	.....
	1891	10.0	8	.....
	1908	10.6	8	.....
Mean			13	4
11 inches or more	1890	12.3	15	.....
	1897	11.3	8	.....
Mean			12	-1
Mean change				2.5

TABLE NO. 16.

This table groups the data when the rainfall was above the normal for February and March, by 10-year and 25-year periods, and shows plainly that instead of a tendency toward increase of flood days in recent years there is actually a decrease, with the same precipitation.

As shown by the last sentence in the discussion of Table 15, the average increase in flood days is 2.5 with each increase in precipitation of 1 inch. Then if 8.2 inches of rain from 1861 to 1885, inclusive, caused 6.5 flood days each year, the rainfall of 9.2 inches from 1886 to 1910, inclusive, should have caused 2.5 days more or 9 flood days each year. But, because the tendency to flood conditions is less, the increase of 1 inch of rain produced an increase of only 1.6 flood days per year.

Applying the same average increase of 2.5 days for each increase of 1 inch in rainfall, or 0.25 day for each increase of 0.1 inch of rain, it will be seen that the number of flood days in the 10 years, 1901 to 1910, inclusive, is exactly the same as the flood days in the 10 years, 1861 to 1870, inclusive, if the difference in rainfall is taken into consideration, and is 2.75 days less than was produced in the 10 years, 1881 to 1890, inclusive, after making allowance for the difference in rainfall.

TABLE 16.—*Precipitation and days with river above 50 feet during February and March, by 10-year periods, Ohio River, Cincinnati, Ohio, 1861-1910, inclusive.*

Year.	Year.	Precipitation.	Days.
1861 to 1870, inclusive.....	1862	7.7	0
	1863	7.1	0
	1865	7.4	5
	1869	7.1	0
	1870	7.3	0
	1867	10.0	19
Mean.....		7.8	4
1871 to 1880, inclusive.....	1874	7.6	0
	1879	7.1	0
	1880	8.0	4
Mean.....		7.6	1
1881 to 1890, inclusive.....	1881	7.2	2
	1887	9.4	13
	1882	10.1	9
	1883	10.2	16
	1884	10.2	19
	1890	12.3	15
Mean.....		9.9	12
1891 to 1900, inclusive.....	1893	7.4	8
	1899	8.4	7
	1898	9.3	7
	1891	10.0	8
	1897	11.3	8
Mean.....		9.3	8
1901 to 1910, inclusive.....	1910	7.3	3
	1907	7.0	11
	1904	8.0	0
	1906	8.9	9
	1903	9.9	8
	1908	10.6	8
Mean.....		8.6	6
Mean, 1861 to 1885, inclusive.....		8.2	6.5
Mean, 1886 to 1910, inclusive.....		9.2	8.1

TABLE No. 17.

In Table 17 the average rainfall and average number of days with the river below 10 feet in August, September, and October is tabulated for differences in rainfall amounting to 1 inch. This shows that the average increase in low-water days with each decrease of 1 inch of rain is 7.

TABLE 17.—*Average precipitation and days with river below 10 feet for August, September, and October for each inch of rain, Ohio River, Cincinnati, Ohio, 1861 to 1910, inclusive.*

Precipitation—	Mean precipitation.	Mean days.	Change.
Below 5 inches.....	4.3	86	.....
Between 5 and 6 inches.....	5.4	89	+ 3
Between 6 and 7 inches.....	6.6	79	-10
Between 7 and 8 inches.....	7.4	72	- 7
Between 8 and 9 inches.....	8.5	79	+ 7
Between 9 and 10 inches.....	9.5	77	- 2
Between 10 and 11 inches.....	10.4	49	-28
Above 11 inches.....	13.3	36	-13
Mean.....			- 7

TABLE NO. 18.

In Table 18 the average rainfall and average number of days with the water below 10 feet in August, September, and October is given for each 10-year and each 25-year period. Remembering that the increase in low-water days amounts to an average of 7 a year with each decrease in the rainfall of 1 inch, it will be seen at once that the number of low-water days during the 10 years from 1901 to 1910, inclusive, were less than in any of the preceding 10-year periods, taking into the account the difference in rainfall. Also that during the last 25 years the average number of low-water days is 9.1 less than would have been produced in the first 25 years with the same amount of rainfall. Or, the tendency to produce low-water conditions in the Ohio River has been 14 per cent less during the 25 years from 1886 to 1910, inclusive, than during the 25 years from 1861 to 1885, inclusive, with the same rainfall, as calculated during the low-water months of August, September, and October.

TABLE 18.—*Average precipitation and number of days with river below 10 feet for August, September, and October, by 10-year and 25-year periods, Ohio River, Cincinnati, Ohio, 1861-1910, inclusive.*

Year.	Precipitation.	Days.
1861 to 1870.....	10.1	60
1871 to 1880.....	8.5	74
1881 to 1890.....	9.7	60
1891 to 1900.....	7.3	74
1901 to 1910.....	7.7	63
1861 to 1885.....	9.3	66
1886 to 1910.....	8.0	66

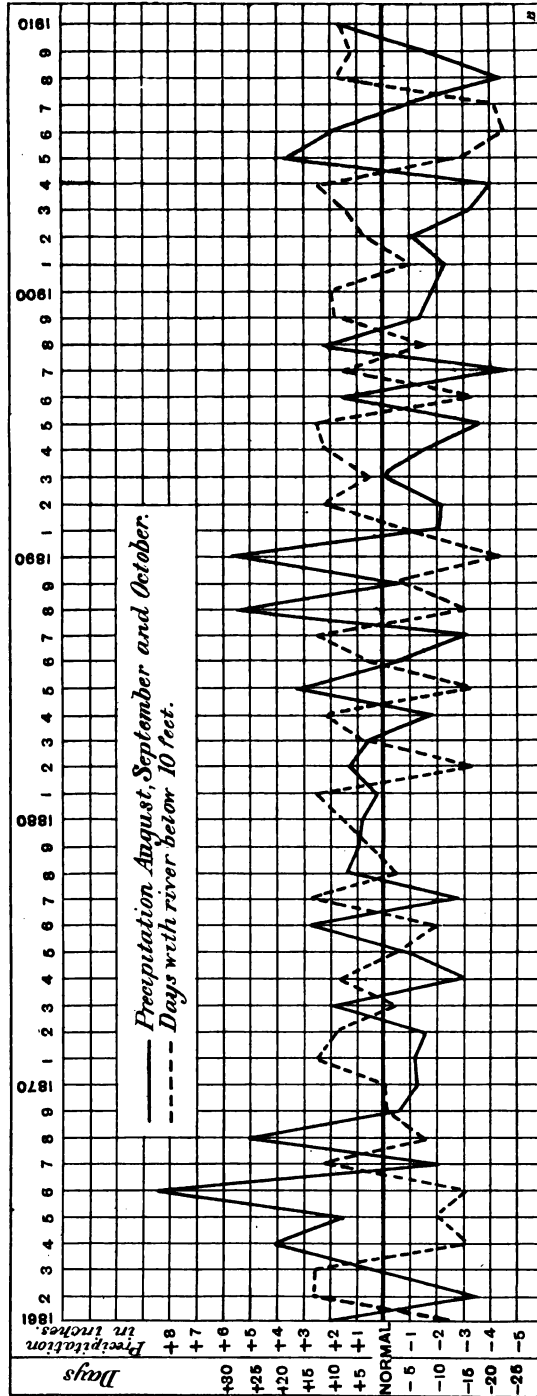


CHART 2.—Relation between precipitation and the number of low-water days during the driest period of the year.

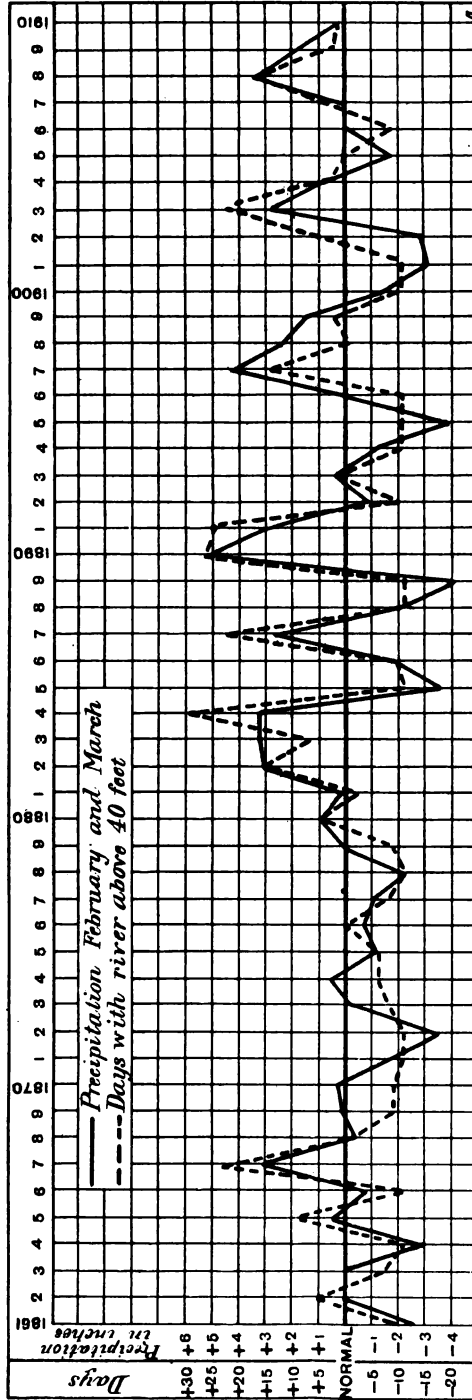


CHART 3.—Relation between precipitation and the number of high-water days during the period of highest water.

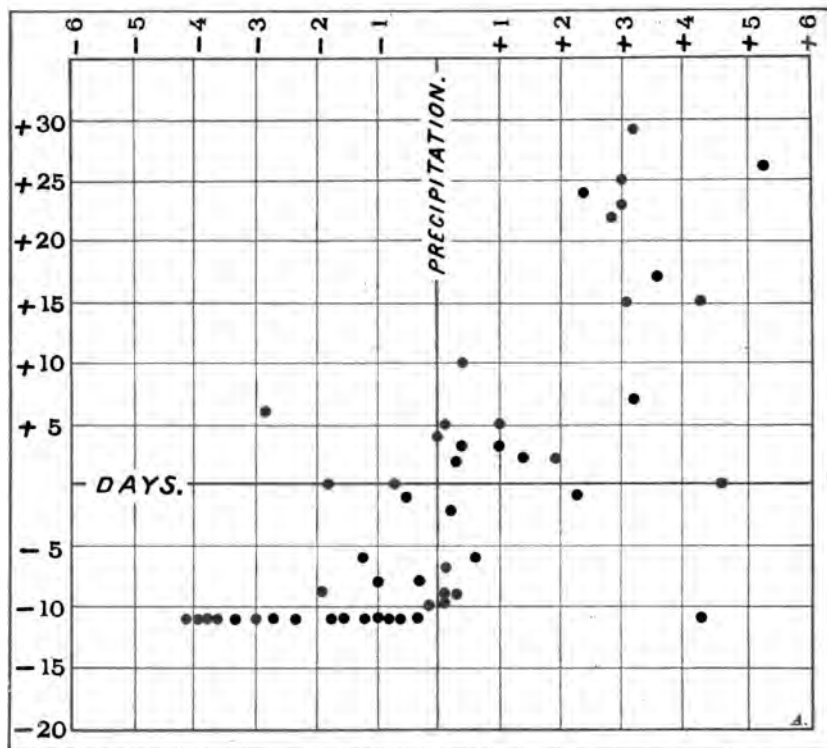


CHART 4.—Departures from normal precipitation during February and March and number of days with the river above 40 feet.

Bulletin No. 41.—W. B. No. 473.

Issued February 27, 1912.

U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.

FORECASTING FROST IN THE NORTH
PACIFIC STATES.

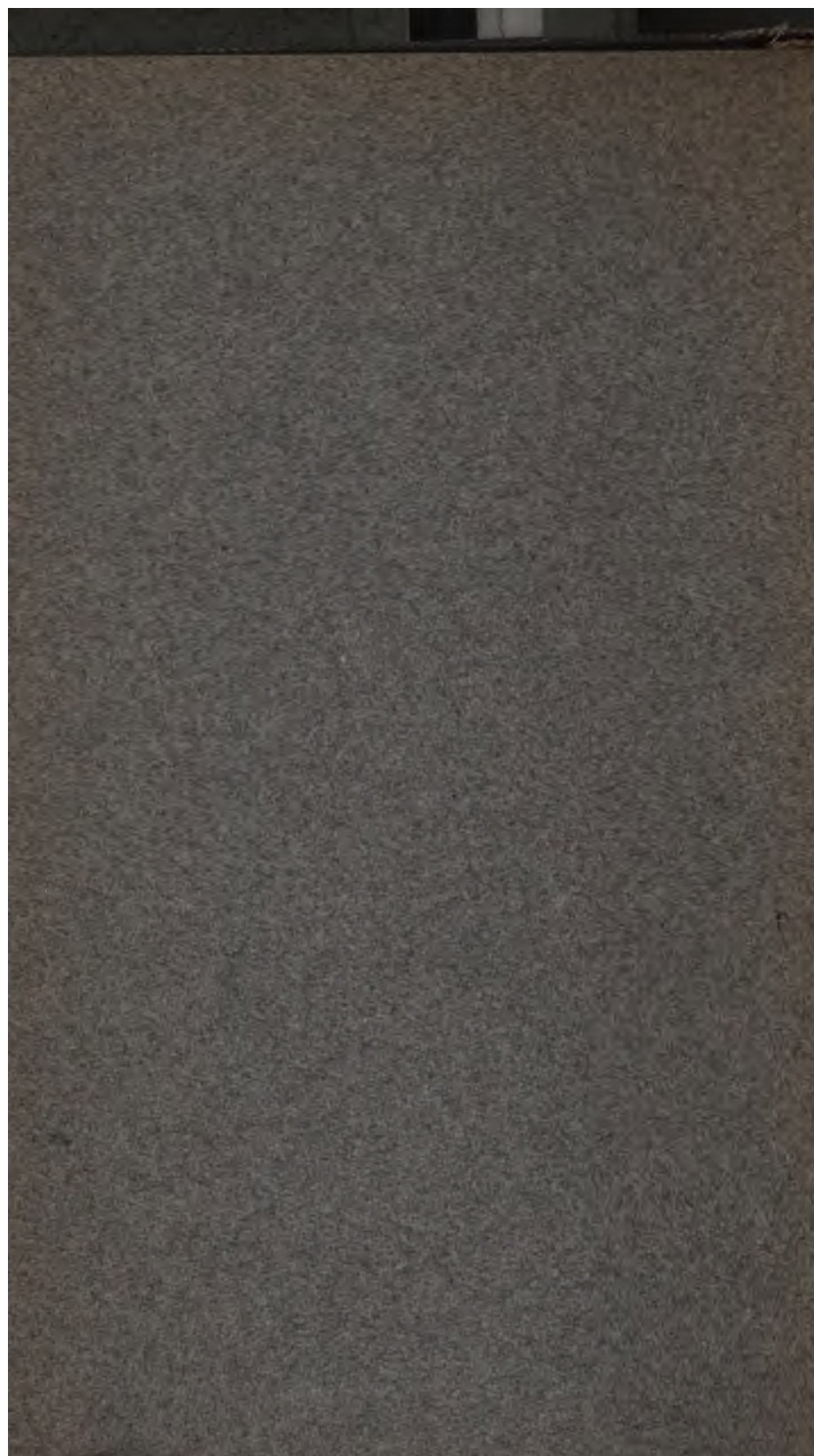
BY

EDWARD A. BEALS,
DISTRICT FORECASTER.

Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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THIS PUBLICATION may be procured from the Superintendent of Documents, Government Printing Office Washington, D. C., at 10 cents per copy.

LETTER OF TRANSMITTAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU, OFFICE OF THE CHIEF,
Washington, D. C., December 2, 1911.

The honorable SECRETARY OF AGRICULTURE.

SIR: I have the honor to transmit herewith a paper entitled "Forecasting Frost in the North Pacific States," which has been prepared by Mr. Edward A. Beals, district forecaster of the Weather Bureau.

The paper describes the evolution of the system of frost warnings for the protection of fruit in Washington, Oregon, and Idaho, and contains detailed reports of the conditions under which warnings were issued during the critical season in the spring of 1911 for the fruit districts of Boise, Lewiston, Rogue River Valley, and Yakima Valley. It discusses the meteorological conditions which afford an indication of the probable occurrence of frost and on which warnings may be based. The paper is accompanied by three illustrations showing Weather Bureau equipment for observing temperature conditions, sketches of the four fruit districts mentioned, five weather maps showing the conditions preceding frost, and a chart of composite thermograph curves.

It is thought that the paper contains valuable information to the fruit growers in the States named, and it is therefore recommended that an edition of 2,500 copies be issued for distribution in those regions.

Very respectfully, your obedient servant,

WILLIS L. MOORE,
Chief United States Weather Bureau.

Approved.

JAMES WILSON, *Secretary.*

FORECASTING FROST IN THE NORTH PACIFIC STATES

By EDWARD A. BEALS.

Historical.—According to Boussingault, the celebrated French chemist, smudges have been used for centuries on the plains of Cusco on still clear nights by Indians to retard the loss of heat from the soil, and it is thought that the same or similar methods have been used in Europe for an equally long period. It is only in recent years, however, that the matter of frost protection has been scientifically investigated, and for literature on the subject the reader is referred to Farmers' Bulletin No. 104, Bulletin T, published by the Weather Bureau, and to various articles in the Monthly Weather Review.

Fruit raising in the north Pacific States has increased enormously in the last few years, and the number of trees that will come into bearing in the next five or six years will increase the acreage at least tenfold. In the early days of the industry the principal crop was prunes, and the large orchards were mostly in the humid sections of Oregon and Washington. There were very few large apple and peach orchards, and those in bearing were nearly all located where the air drainage was good and the losses by spring frosts were infrequent. In the case of prunes many of the growers believed that when they had short crops the damage was done by cold rains during the blossoming period, which prevented the bees from carrying pollen to the stigmata, and the fruit did not set on that account, rather than because of injury by frost.

For these reasons very few growers a few years ago made any attempt to protect their orchards from frost, and those that did were not very successful, as their methods were crude, and where the necessity was greatest the orchards were badly located and the task was almost hopeless from the start. Frost warnings were issued by the Weather Bureau during this time, although very little attention was paid to them, as foreknowledge of frost is of practically no benefit to the horticulturist unless he is prepared to protect his crop from threatened injury.

In 1907 Mr. P. J. O'Gara, one of the scientific assistants in the Bureau of Plant Industry, was sent to the Rogue River Valley to study the pear blight, which was making inroads among the pear

and Spitzenberg apple trees in that section of the country. He quickly realized that the fruit growers were losing much more fruit by spring frosts than they were willing to acknowledge, and being familiar with orchard-heating methods in California, he soon induced a number of orchardists to adopt similar methods in the Rogue River Valley. The plan was so successful the first year that it was tried the next on a fairly large scale and with even greater success. In the meanwhile a few orchardists in other important sections had taken up this work, and by the spring of 1910 the movement had obtained large proportions in four important fruit centers, viz, Rogue River Valley, Yakima Valley, Lewiston orchard district, and the Boise orchard district.

As soon as an orchardist was prepared to heat his orchard the question of accurate frost warnings became of paramount importance, and as the number increased the question became accentuated. The owners and managers of these orchards had gone to the expense of thousands of dollars for material to insure their crops from damage by frost, and they were not satisfied with a warning classified as a light or a heavy frost, where in the one case the minimum temperature in a standard thermometer shelter was expected to remain above 32° and in the other sink below that point. They want to know just how cold it will get and just when it will be necessary to start their fires. They also want this information as far ahead of each impending frost as possible.

The district forecaster had been making forecasts of light and heavy frosts, basing his verifications upon thermometer readings at Weather Bureau reporting stations; those for the Rogue River Valley being based upon reports received from Roseburg, Marshfield, and Siskiyou, all some distance away and where the thermometers were exposed in shelters at different elevations above the ground; those for Boise upon reports from readings taken in an instrument shelter on the roof, 78 feet above the ground; those at Lewiston over sod, 10 feet above the ground; and those for Yakima from the station at Walla Walla with thermometers located on the roof, 62 feet above the ground.

These irregular exposures which in some cases were many miles from the place where we were to look for accuracy in results made it necessary to weigh the forecasts by further estimates as to the differences that would probably prevail between the temperatures at the reporting stations and those in the orchards being protected. We could obtain average differences by studying the cooperative observer's records at near-by stations, but these were unsatisfactory, and it was soon found that to get best results we had to put stations in the heart of the orchard districts, and then there were large differences to be calculated at places not very far apart.

Accordingly, early in 1911 the Chief of the Weather Bureau authorized the writer to make an investigation of the subject with a view to localizing the work and improving the forecasts. The foregoing four localities were selected for the first year's work and a number of "key" stations were established in the heart of the different districts. (See Fig. I, Fig. II, and Fig. III.) It was necessary to employ temporary observers to look after the "key" stations and to send a trained man to North Yakima to look after the work in that valley. In the Rogue River Valley we were fortunate in securing the services of Mr. P. J. O'Gara, who had made a special study of the frost conditions in that section and was familiar with the topography in every orchard for many miles around Medford, Oreg.



FIG. I.—"Key" station, Boise, Idaho.

An abstract of the reports from the different localized centers follows:

Medford (by Mr. P. J. O'Gara). (See Diagram A.)—We have had a hard pull of it, but in every case where the growers had properly prepared for the fight they have won out. A careful examination of the orchards above the valley floor shows scarcely any damage excepting in some peaches and the Bosc pears, which are most easily injured. However, even the Bosc pears will have quite a good crop. On the valley floor, especially during the mornings of April 14, 15, and 29, the fight was a hard one. However, the lowest drop of 22° to 24° was for such a short time that, in the main, 25° and 26° were the temperatures

against which we were contending. The fact that there was little or no wind movement was a tremendous advantage to those heating the orchards. The loss



FIG. II.—“ Key ” station, Lewiston Orchards, Lewiston, Idaho.



FIG. III.—“ Key ” station, Parkers Bottom, Yakima Valley, Wash.

on the valley floor is very light, because practically all the growers who had anything to save did their work. Two or three were not fully equipped, but it

was not because they had not been advised better. They had their own way about it in the matter of the number of fires, and now they see their folly. At this time it looks as though we are to have a better pear crop than last year.

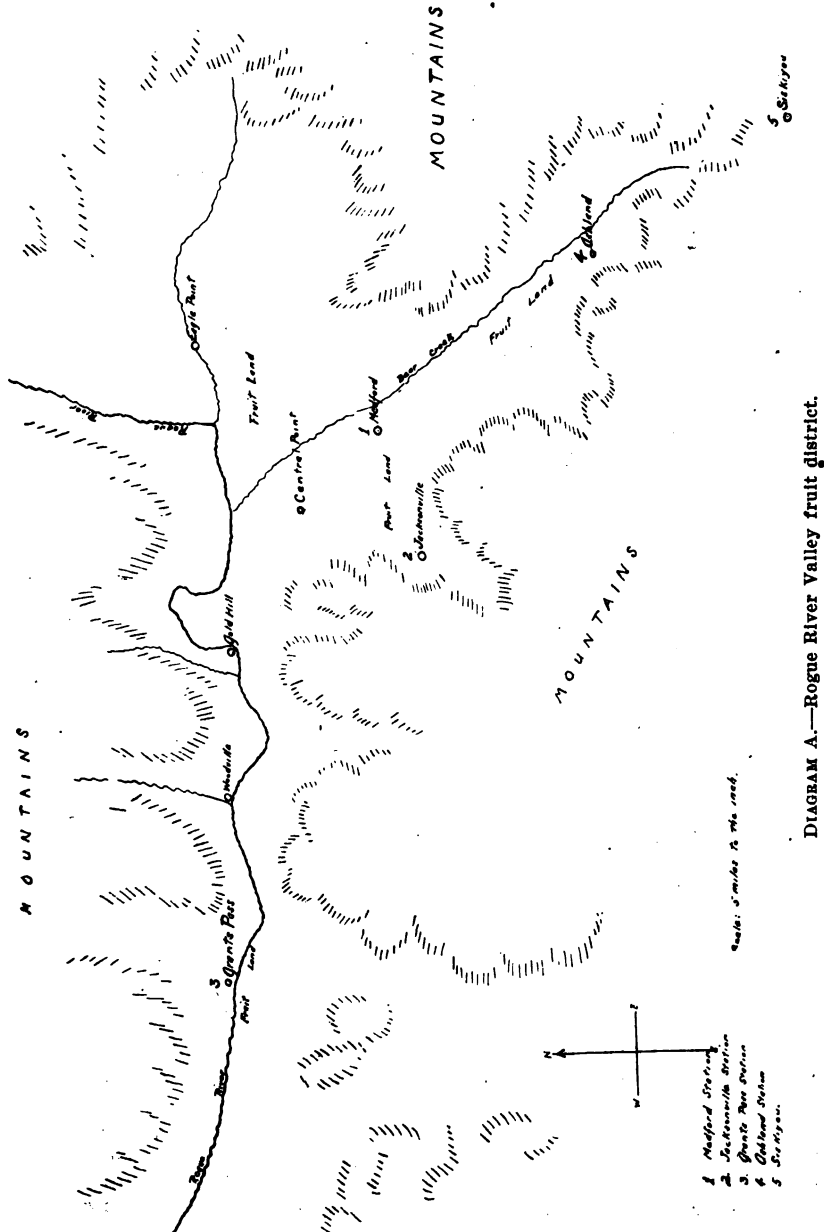


DIAGRAM A.—Rogue River Valley fruit district.

The apples bloomed very light, and any shortage of the apple crop may be attributed to this cause.

The fruit growers one and all appreciate our work. From April 10 to 16, inclusive, I did not take off my clothes. There was so much anxiety on the part

of everyone that I felt it my duty to stay up night and day and help the growers out. On the mornings of the 11th, 12th, and 13th I was very much afraid the growers would waste their fuel unnecessarily, and knowing the possible chances for much lower temperatures on the following days, namely, the 14th and 15th, I constantly urged them by telephone to refrain from firing whenever the temperature ranged no lower than 29° in the orchards. The saving of fuel proved to be the saving of the crops, because many had not laid in a supply for more than three firings. In instructing them to fire I had them light only as many fires or pots as would hold the temperature above danger. The local forecasts were very accurate both as to time and minimum temperature to be expected. I always indicated the time it would be necessary to begin firing and had the

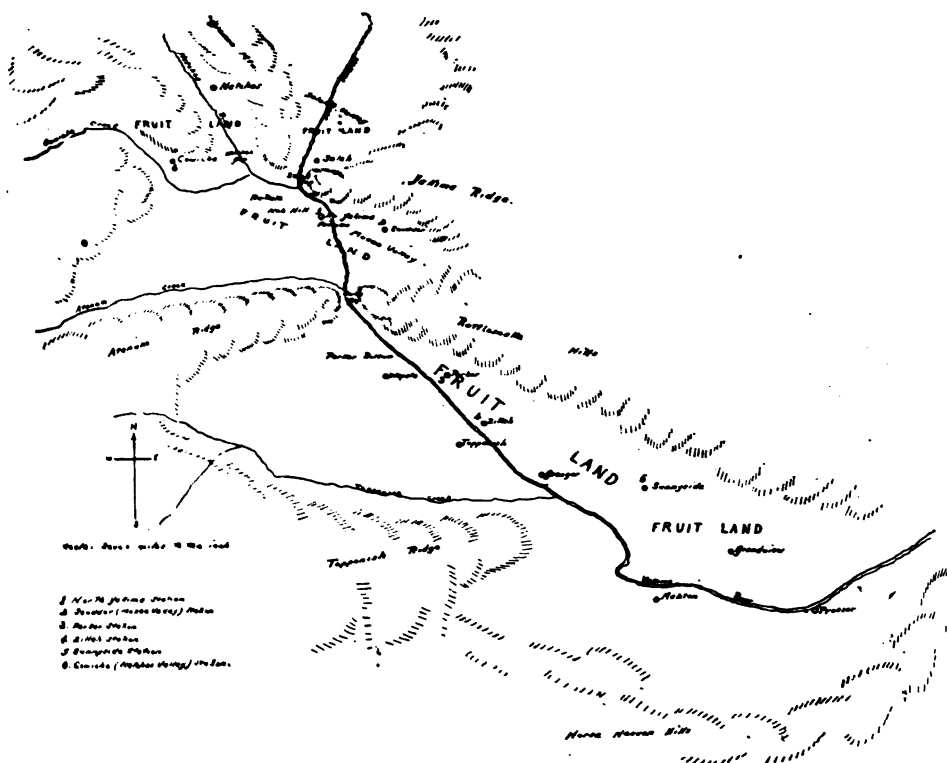


DIAGRAM B.—Yakima Valley fruit district.

growers set their alarms for that hour. In many cases I called them up during the early morning hours to warn them of their danger. We believe we have been successful, and although a few have lost some fruit, it is not because of any fault of ours. The instructions as to how to prepare were all that previous experience had taught us, and the forecasts were timely and accurate.

It is rather early to estimate what we have saved, but a half million dollars will not be far from the gross value saved this year.

North Yakima (by Mr. Thomas R. Reed). (See Diagram B.)—The work of protecting orchards against freezing temperatures by artificial means has been practiced for only a few years in the Yakima Valley—two I think—in the lower, and this season is the first in the upper valley. With many, therefore, it is still

in its experimental stages, while with others the work has become an established feature of annual occurrence. The number who fire their orchards has increased each year since the work began and it is safe to say that after this season's experience a vastly larger number will prepare to protect their blossoms than ever before.

The issuance of accurate predictions is a matter of vital importance to these people and the demand for the forecasts during last season has fully justified the newly inaugurated service of the Weather Bureau. The warnings have been distributed to the public from the exchanges of the Pacific Telephone & Telegraph Co. and the Yakima Valley Telephone Co. Manager Jones of the former and Manager Bartholomew of the latter have been courteous in lending us their cooperation. Warnings were issued for the following places: North Yakima, Moxee, Parker, Zillah, and Sunnyside, and were placed on the following exchanges: North Yakima, Wapato, Toppenish, Zillah, Granger, Sunnyside, Grandview, Prosser, Mabton, and Pasco. Forecasts were attempted for the first five named stations only, because observational data were procurable from these. The first two and the last, i. e., North Yakima, Moxee, and Sunnyside, are regular reporting cooperative stations of the Weather Bureau; Parker and Zillah stations were specially established for the work this spring. All stations were equipped with standard maximum and minimum thermometers; the North Yakima, Parker, and Sunnyside stations with exposed thermometers, and all except Parker with rain gauges.

Regular telephone reports of temperature and weather were received from these stations and from the Reclamation Service station at "Tieton headquarters" in the Naches Valley. The Reclamation Service officials have been particularly ready to respond to any requests made upon them for assistance, and Mr. Remington of Sunnyside and Mr. Nolan at Tieton headquarters deserve credit for the regularity with which they have forwarded messages each evening from their respective stations.

The meteorological conditions favorable for frost in the Yakima Valley include the usual conditions of high barometer following a spell of cloudy, cold weather in which the soil has lost its accumulated heat, clear sky, and very light or no wind. It is considered by local observers that frost is most likely to follow a period of bad weather and the shift of wind from the south or southwest into the northwest or north. It is popularly supposed that danger of frost is small unless the veering to northerly quarters has been preceded by quite a marked period of southerly wind. This of course may be a colloquial way of indicating the necessary intensity and duration of the cyclonic low occupying the northwest; but it is worthy of note that judging from observations this season, dangerous frost is not likely except following protracted cloudy and cold weather, and that all the really serious frosts of the season have followed days on which the maximum temperature has been under 65° and the current temperature under 60° at the time of the afternoon observation.

High barometer alone, while causing frost in other localities in the State, has repeatedly failed to bring freezing temperatures to this valley, attributable partly, perhaps, to active air movement often occurring in connection with anti-cyclonic weather. A freeze may occur here when the Northwest is occupied by low pressure; in fact, when a rain forecast would seem more legitimate than a frost warning, as on the night of the 6th of April; but this is an uncommon condition. Under such conditions the barometer may show no fluctuations worth speaking of, the surface currents may be from the south, in fact nothing to warrant a frost warning being issued except the fact of a clearing sky and a sharp fall in temperature.

The forecaster has then to determine whether the wind is to remain light and the sky clear, and this is an extremely precarious undertaking. Perhaps the diurnal rise in the barometer occurring at the time his decision is being made adds to the difficulty; and he must be able to distinguish to a certain extent between the periodic and the unperiodic movement, for it is the latter upon which he depends in a large measure to foretell the condition of the sky. Under such conditions, and unless the forecaster is sure of his position, it is wiser to place on their guard those who wish to protect their orchards, for the growers would rather be warned a few times unnecessarily than to have freezing temperatures descend on their orchards without forewarning.

The freeze occurring on the morning of April 6, when the temperature at North Yakima dropped to 25°, could scarcely be foreseen, either from the weather map or from local observations, but it is a type of local freeze which should be studied and for which the local observer should be constantly on guard. Although on this occasion the warning for North Yakima was for light frost only, no one failed to fire. Warnings for Moxee, Zillah, and Sunnyside were for freezing temperatures and firing was general throughout the lower valley. Much injury was sustained by unsmudged orchards and some orchards were injured where sufficient pots were not in use.

The ensuing freezes, which occurred with unusual frequency and severity for this section, were more easily foreseen. Between the inclusive dates of April 5 and 15 nine heavy frosts were recorded in North Yakima, and during the first half of the month there were more than this number in the neighborhood of Moxee and on the low ground below Union Gap. Seven times the minimum temperature dropped to 28° or lower at the North Yakima station. The severest freeze of the entire period occurred on the morning of the 13th of April. The North Yakima station registered 24°; in Moxee 16° was reached, and the temperature in the lower valley ranged from 17° at Sunnyside to 23° at Parker Heights. This freeze ended the firing for the season with a large number of orchardists, for attempts to cope with such conditions were futile, except on topographically favored land. On the higher lands, however, especially in the Parker Heights and Zillah districts, much fruit was saved by firing.

On the two mornings following what was very nearly a repetition of the phenomenal temperatures of the 13th was experienced. Orchardists prepared for only three nights' firing were required to procure more oil and those depending on the supply in North Yakima were unable to do so, as the amount there was insufficient. The big storage tanks in the lower valley, especially at Granger, Wapato, Outlook, and other points, enabled the growers to continue the orchard firing until the last freeze was past. It was undoubtedly a strenuous period for the fruit men and one which is not likely to be repeated for many years. It showed the necessity of using an ample number of smudge pots and also the value of orchard firing on a large scale, showing the greater ease of heating a large district than a small one, or one in which heating is practiced only in a sporadic way.

North Yakima men were unsuccessful in maintaining safe temperatures, partly because they used too few pots—generally about 40 or 50 to the acre—and partly because each heated orchard was surrounded by unheated ones, and the wind, which was a feature of several frosty nights, effected a dispersion of heat and smoke. When practically all the orchardists fire, windy conditions can much better be coped with. On the morning of the 11th in particular orchardists reported that whereas under ordinary circumstances they could raise the temperature 6° to 7° with 55 pots to the acre, on this morning

it could only be raised 3°. On the south slope of Nob Hill the smoke blew rapidly away, scarcely reaching the lower branches of the trees.

It was on this night (10th-11th) that the severest freeze occurred in the Nob Hill and Fruitvale districts, which are generally least affected by frost, the former being considered immune. The thermometer in the Weather Bureau shelter in North Yakima registered 29° and in Moxee 28°; 31° was reported from Parker, 28° from Zillah, and 33° from Sunnyside. That conditions as usually experienced suffered a complete reversal will be seen when it is stated that the temperature on Nob Hill and Fruitvale varied between 20° and 23°. The reports from these districts showed much uniformity and many readings were made from reliable instruments. Moxee—notoriously cold—varied only a degree from North Yakima, and Sunnyside, which more often corresponds with Moxee, was even warmer. An interesting problem is here presented and its solution may disclose some interesting facts. The following is suggested by observations this spring:

A study of a topographic map of the region should be made in order to appreciate the situation. The Yakima Valley is inclosed on all sides by mountain ranges varying from 2,500 to 3,000 feet in height and higher in the Cascades to the west. Access is had to the valley by two gaps on the north and one on the south. Nocturnal air drainage will always be from north to south under normal conditions, following the slope of the land, and observations show this actually to be the case. Fruitvale and the northern slope of Nob Hill are the first to benefit by the northwest breeze from the Naches Canyon, as they lie directly in its course and in close proximity to the Naches Gap, from which it issues. There may be a similar breeze from Selah Gap, a little to the eastward, but observations do not cover this point, nor are there any extensive orchards in line with Selah Gap to benefit by such a breeze if there were one.

The Naches Valley above Naches Gap forms a natural reservoir for the air drainage from a vast mountainous area, and it is natural to conclude that when the convergent air is expelled into the Yakima Valley below through the outlet formed by Naches Gap a mixing of the air and possibly an adiabatic warming ensues, which would account for the comparatively higher temperatures encountered in the region lying directly in its path, as at Fruitvale, and the comparatively lower temperatures in the Fairview and Moxee districts, which lie several miles southeast of Fruitvale.

The Weather Bureau station is located in the city of North Yakima, and, therefore, between the two districts under discussion, Fruitvale being northwest of the city and Fairview and Moxee southeast. The thermometer at this station strikes a pretty fair mean, for while Fairview is often 2° and Moxee 5° to 8° colder than the North Yakima station, Fruitvale is usually a few degrees warmer. As the breeze from Selah Gap spreads out and flows across the valley it loses its force, its temperature is lowered by radiation, and with further southeastward movement its character is changed from a protective wind to a more or less destructive one.

On the morning of the 11th, when the conditions in these districts reversed, a freezing wind was blowing from the south and southwest, having blown from this quarter throughout the night. There was no counter breeze from Naches Gap, and the minimum temperature reported from the Naches Valley above, a district from which comparatively high temperatures are usually looked for, was 22°. Thus it appears that strong connection exists between a reversal of the customary wind direction and a reversal of temperature conditions in the several localities under discussion.

I would recommend the resumption of the "key" stations at Parker, Zillah, and Sunnyside next season, and also that a station be placed in Grandview or Prosser to report daily by mail, for if forecasts are to be issued for these districts it will be necessary to have data from them.

Some of the telephone exchanges, as at Zillah and Granger, for instance, close at 9 p. m., so it is necessary to issue warnings as early as possible and avoid the necessity of modifying them at a later hour. An improvement can be effected in quicker transmission of the forecasts from Portland. It might be that by sending them by telephone they would be subject to less delay in transmission and could be placed before the public nearer 7 than 8 p. m.

In the past firing has been largely confined to the country below Union Gap, the number of pots in use being estimated at 70,000, 26,000 of this number being purchased this year. Many more orchardists in both lower and upper valleys will fire next season, and the forecaster will have greater opportunities for being of service to the individual orchardist than was possible this year. This year the field of maximum activity was rather remote and personal advice on critical nights was not feasible. However, those above the Gap kept in touch with me as long as they continued to fire and made things pretty lively. The forecasts gave general satisfaction this year in spite of its being the first year's work and performed somewhat blindly in the absence of reliable data. The work should be much easier next year and in succeeding years as local observational data accumulate and experience is acquired. A feature of the work very valuable to the fruit men is the morning forecast during protracted frost spells, for by it the grower is advised as to the need of hauling oil before nightfall.

Firing above the Gap was practiced for practically the first time this year. It resulted in a general failure to maintain a temperature of anything near 23°, and the orchardist learned the lesson that too few pots are worse than none at all, since they do not save the fruit and are a great expense.

In many orchards, on the night of the 11th-12th, the temperature had fallen to 23° by midnight, remaining below that point for seven hours; and to save the crop it would have been necessary to start a reserve number of pots before daylight to replace those that had burned out. It is difficult to estimate the loss, for the reason that the crop this year was not expected to reach that of last by any means; it being an "off year." Mr. Thompson's estimate of 1,100 cars is generally conceded to be too low. Last year about 3,000 cars were sent out from the Yakima Valley, and the general belief is that the shipment this year will be in the neighborhood of 2,000, making the total value of the crop very close to \$1,500,000. Any estimate of the loss from frost is impossible at this date, for I have seen a full crop of apples, peaches, and pears in one orchard and found the entire crop destroyed in another close by. Every orchard in the valley would have to be examined to make a correct forecast of the losses by frost.

How many took advantage of the service it is not possible to say, but the girl who handled the forecast distribution says that she was literally swamped with calls between 7 p. m. and 9 p. m. on critical nights. Since this interest was manifested by those who do not fire, it is easy to see what would be the interest taken by the increasing number who expect to engage in orchard protection in succeeding years. Beyond question it is desired to have the newly inaugurated frost service continued next season. It has required the first season to wake up the people to their part in the work, and to the value of orchard heating even in comparatively safe districts; next year will witness their greater dependency on the Weather Bureau service, and greater accuracy and assurance on the part of the forecaster assigned to this locality.

Boise (by Mr. Edward L. Wells). (See diagram C.)—The Boise Valley is well suited to the growing of such fruits as apples, pears, prunes, sour cherries, and common berries. Some fruit has been grown in the valley for many years, but it is only within the last few years that scientific fruit growing on a commercial scale has become an important industry.

While the entire region is more or less subject to spring frosts these frosts are rarely sufficiently severe to cause widespread damage. For this reason, prior to 1909, comparatively little attention was given to measures to protect fruit from frost injury. The spring of 1909 was one noted for a succession of damaging frosts, resulting in almost a complete failure in many orchards. This failure turned the attention of the growers toward protective measures, and some of the more progressive of them provided themselves with oil pots and

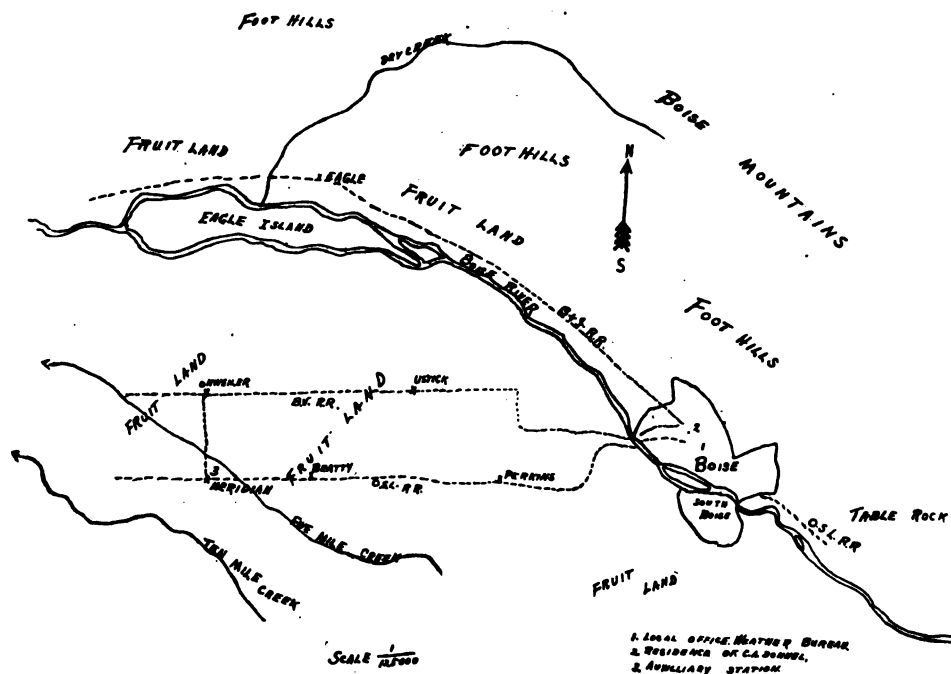


DIAGRAM C.—Boise Valley fruit district.

oil for use in 1910. The spring of 1910 was much more favorable for fruit than that of 1909, so much so that there was a good yield of fruit in most of the unprotected orchards, as well as in those that were protected. This being true, there was little increase in 1911 over the area heated in 1910; the entire area in the upper part of the valley adjacent to Boise probably not exceeding 1,000 acres. Like that of 1910, the spring of 1911 was not a good one to demonstrate the efficiency of protective measures, for while some very low temperatures were experienced, these low temperatures occurred when the buds were least susceptible to injury, and little damage occurred that could be directly traced to frosts.

It is probable that orchard heating will not become common in this valley as it is in the Grand Valley in Colorado and in the Rogue River region in Oregon, until another season like that of 1909 is experienced, when the practical value of heating can be demonstrated. It is believed, however, that the time will come when orchard heating will become general in the Boise and neighbor-

ing valleys, and the Weather Bureau should anticipate the demand for accurate information that this condition will bring about by enlarging the number of auxiliary stations and carefully studying the frost problems in every locality where fruit is grown.

The topography of this region is peculiar and gives rise to some weather conditions that make frost forecasting a difficult matter. The Boise River, in its upper reaches, flows through a rugged mountainous region. About 6 miles southeast of Boise it emerges from a deep box canyon, the mouth of which marks the head of what is known as the Boise Valley, which extends thence northwestward with increasing width toward the Snake River. Northeast of Boise are the Boise Mountains, reaching in 12 miles an elevation of 7,500 feet, or 4,800 feet above the city. Toward the southwest the ground rises in a series of widening benches. Through this bench land, where most of the large orchards are located, run several water courses, rather unimportant naturally, but forming a means for air and water drainage, and apparently playing an important part in determining local temperatures on frosty nights. The entire region may be classed as arid, having approximately 13 inches of precipitation annually at Boise, and somewhat less at points away from the mountains. Water for irrigation is supplied by the Boise River.

In fair weather there is quite a noticeable mountain and valley breeze blowing down the valley, or from the southeast from early morning to about 10 a. m., and up the valley or from the northwest in the afternoon. Frosts occur ordinarily upon the approach of a strong high-pressure area from the northwest. The outflow from this high, combined with the ascending currents already mentioned, make a strong northwesterly wind in the afternoon, which has come to be considered as the surest indication of frost. At night, in addition to the ordinary nocturnal lessening of the wind velocity, the descending current opposes the outflow from the high, causing a stagnation of the air highly favorable for the occurrence of low temperatures near the ground. At such times there is a noticeable tendency for the colder air to settle into the shallow depressions along the water courses already mentioned. When conditions for rapid radiation are particularly favorable no two thermometers in the valley will indicate the same temperature. At other times the distribution of temperature is fairly uniform. Whenever there is any considerable amount of wind at night frost does not occur.

TABLE I.—*Frost observations, Boise, Idaho, 1911.*

Date.	Lawn temperature, Boise, 8 p. m.	Dew point, Boise, 8 p. m.	Relative humidity, Boise, 8 p. m.	Dew point, Boise, 5.20 p. m.	Dew point, Meridian, 5.40 p. m.	Expected minimum temperature.	Minimum temperature, Boise, following.	Minimum temperature, Meridian, following.
Apr. 12.....	32	25	73	26	21	20	20	18
13.....	38	26	59	11	10	22	21	20
13.....	¹ 36	¹ 18	¹ 45					
14.....	46	16	27	10	10	26	26	28
16.....	54	28	37	22	20	32	28	30
21.....	51	33	50	28	32		33	35
May 6.....	52	32	47	28	32	30	36	39
8.....	53	32	44	38	36	32	30	32
9.....	49	30	47	28	25	26	30	29
10.....	53	34	43	34	34	30	35	34
19.....	52	38	61	41	35	32	33	32
24.....	53	34	49	31	32	² 32	31	31
25.....	53	32	44	28	32	30	33	37
26.....	52	38	58	36	37	34	34	34
27.....	57	32	38	32	32	32	34	35
June 4.....	60	32	36	27	33	33	37	36
Mean.....		30		28	28.1	29.4	30.7	31.3

¹ Taken at 10 p. m.

² Not given out. No warning received.

Sometimes when the crest of the high reaches or passes this region before morning an easterly wind will spring up. A brisk easterly wind, coming as it does off the mountain range, partakes of the nature of a chinook. Usually the effect of these chinooks is hardly noticeable except over Boise and the belt of land lying between the foothills and the river. Sometimes, however, the effect becomes noticeable on the bench lands, and on rare instances the chinook has been known to pass over the city and materially affect the temperature on the bench.

It has long been known that the temperature record made from instruments exposed on the roof of the Government building, 78 feet above the ground, failed to represent conditions as experienced in the orchards. It was known first that on clear, still nights the temperature in the orchards fell to a lower point than that indicated by the roof instruments. It was known also that the dew point as found on the roof gave no index of the expected minimum temperature.

During September, 1910, a record was kept by means of instruments exposed in a cotton-region shelter mounted on the lawn in the rear of the Government building. It was found that the dew point and the following minimum temperatures at this exposure correspond very closely, the minimum being somewhat higher than the 8 p. m. dew point, except when the 8 p. m. relative humidity was above 55 per cent, in which event the minimum was somewhat below the dew point. Later the shelter and maximum and minimum thermometers were removed to the residence of Mr. C. A. Donnel, assistant observer, at 1711 Washington Street, where a record has been kept continuously since January 1, 1911. During the same period a record has been kept at Meridian, a village 10 miles west of Boise, the instruments at the two places having practically the same exposure.

It has been found that during the winter months the mean temperature at the two places is almost the same, but the range is slightly greater at Meridian. Beginning with April, however, the mean maximum and mean minimum at the two places are practically identical. The temperature goes slightly lower at Boise on cold nights and is slightly higher on warm nights.

Beginning with April 1 Meridian was supplied with an exposed thermometer, thermograph, and sling psychrometer in addition to the maximum and minimum thermometers already in use, and the dew-point observations were made daily at about 5.40 p. m., and occasionally at about 8 a. m., till June 15. At the same time dew-point observations were made daily at about 5.20 p. m., and on cold nights at about 8 p. m., on the lawn in the rear of the Government buildings at Boise. The data from both early observations were embodied in the p. m. report sent to Portland at 6 p. m.

At the beginning of the season the ordinary frost warnings from Portland were supplemented by detailed statements of expected conditions as indicated by the afternoon reports. Later this service was discontinued, presumably because of the absence of the district forecaster. These special reports were adapted to the orchard region by the official in charge at Boise and given to the telephone exchanges for distribution and to all interested persons asking for information. The office was kept open for information part or all of every cold night during the season.

For purpose of study a table has been made up (see Table I) giving for cold nights only (a) the lawn temperature at Boise at 8 p. m.; (b) the lawn dew point at Boise at 8 p. m.; (c) the lawn relative humidity at Boise at 8 p. m.; (d) the dew point at Boise at about 5.20 p. m.; (e) the dew point at Meridian at about 5.40 p. m.; (f) the expected minimum temperature as given

out to the public; (g) the following minimum temperature at the residence of Mr. C. A. Donnel, 1711 Washington Street; and (h) the following minimum temperature at Meridian.

It appears from this table, first, that the auxiliary station at Meridian is not needed for the purpose of dew-point observations, the lawn dew-point readings at Boise furnishing practically identical data; second, that the 5.20 p. m. reading, made before taking the regular observation, is too early for best results in the spring; third, that the 5 p. m. dew point on the lawn forms an excellent indication of the expected minimum temperature near the ground when taken into consideration together with the relative humidity and other local conditions. It will be seen that the minimum temperature falls below the lawn dew point when the humidity is high and is relatively higher when the humidity is low.

The experience of the season has shown that it is possible to make a very close forecast of the minimum temperature for a given place. When, however, the forecaster is confronted with the task of advising each grower what temperature to expect in his orchard, the problem becomes much more complex. For instance, on April 13, when the temperature fell to 20° at Mr. Donnel's residence at Boise and to 19° at Meridian, some standard thermometers used by the growers went as low as 12°. Again, on May 25, when the ground temperature at Boise and Meridian alike was 31°, some orchard temperatures as low as 25° were reported. Just how much of this difference is due to topography and how much to faulty exposure it is difficult to say. Some of the growers believe that the Meridian temperatures were too high, owing to the fact that the station was in town. However, as there are no large buildings in the town and no buildings of any kind near the shelter, it is evident that this is not true.

It is probable that the fact that the growers' thermometers are exposed without sufficient shelter, and are therefore subject to error from excessive radiation, may account for the discrepancy. Mr. C. A. Donnel spent the night of May 10-11 in the orchard district making comparative readings, with a view to determine how important this factor was, but the temperature was fluctuating considerably and, without assistance, it was difficult to secure accurate results, and, owing to insufficient office help, no further attention could be given this during the season. From such data as he was able to obtain it is apparent that freely exposed thermometers read from 2° to 3° below the true air temperature. This leaves some little difference to be accounted for by topography.

Lewiston (by Mr. W. W. Thomas). (See Diagram D.)—As has been the custom at this station in past years, the daily papers in Lewiston and the weekly in Clarkston published notices in different issues prior to the beginning of the frost season to the effect that all fruit growers should register their names and telephone numbers at the local office of the Weather Bureau. At the beginning of the season our frost-warning list, made up of the names thus registered, contained the names of all the growers in this district who desired to protect their orchards in any way against frost damage and who could be reached by telephone or otherwise.

The public was also informed through the local press that thermometers would be compared with a standard thermometer at the Weather Bureau station free of charge. A number of growers availed themselves of this opportunity, and upward of 50 thermometers were tested and the owners furnished with cards showing the error at 32°.

For the purpose of a study of the temperature conditions at different points in the valley a temperature station was established in a favorable location in the Clarkston (Wash.) section, 1½ miles southwest of the Weather Bureau sta-

tion. This station, known as "key" station A, was equipped with a standard set of maximum and minimum thermometers, an exposed thermometer, and a thermograph. It was placed in the orchard of Mr. J. H. Clear, who volunteered to take the desired observations. A similar station, known as "key" station B, was established 2 miles southeast of the Weather Bureau station, near the cen-

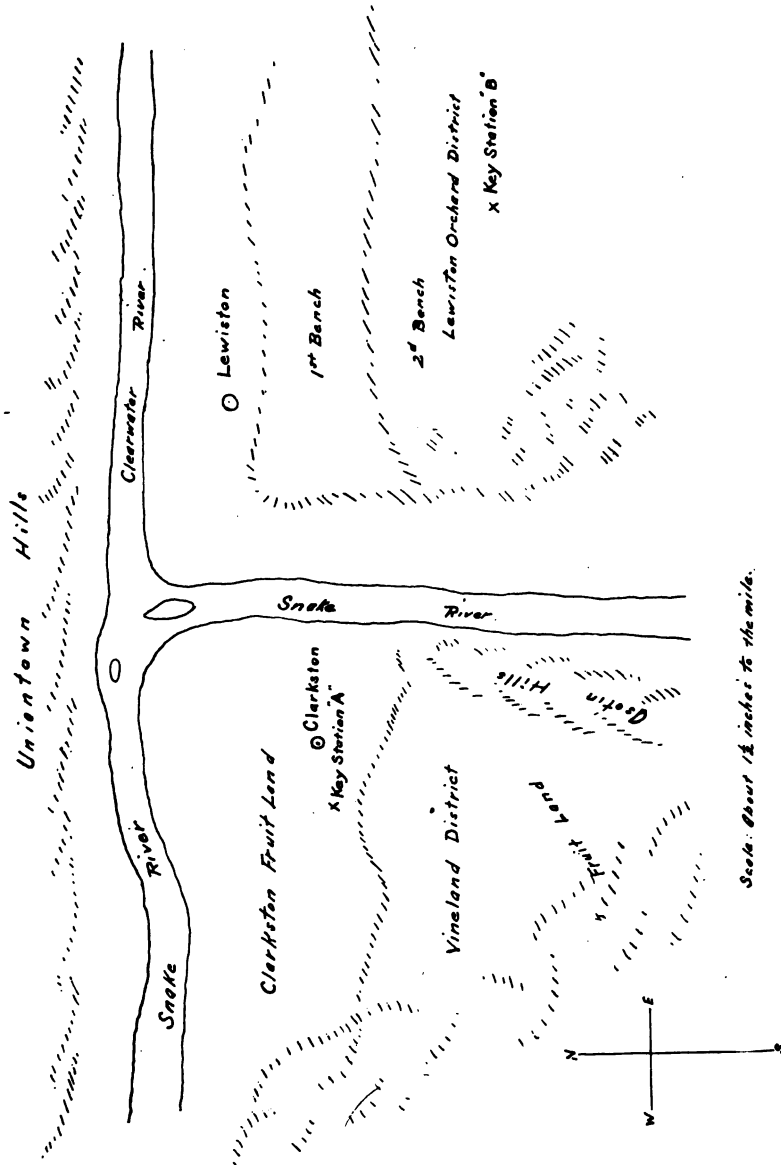


DIAGRAM D.—Lewiston-Clarkston fruit district.

ter of the present bearing orchards in the section known as Lewiston Orchards. It was placed at the home of Mr. P. W. Mullarky and was equipped with a set of Queen & Co.'s maximum and minimum thermometers and a Weather Bureau exposed thermometer. The elevation of station A is 850 feet and of station B, 1,440 feet, and of the local Weather Bureau station 830 feet above sea level.

owing to the fact that orchard heating had never been given a sufficient test in this valley to demonstrate its efficiency, the growers did not take it up to the same extent as elsewhere. In other fruit sections would seem to have waited. However, a number of progressive orchardists provided themselves with devices in the earlier stages of enough destitute.

During the fall of the Lewiston section where there are 2,000 acres in bearing the growers of the orchards were provided with fire pots containing a mixture of kerosene and with smudge material such as prunings, old straw, etc.

During the winter measures were taken in the Lewiston orchards to protect the fruit. The trees were young and it was not desired to have them killed.

During the winter the office of the district forecaster at Portland was in the position of receiving the regular morning forecast or were sent to the growers by a special messenger. Upon the afternoon telegraph service the district forecaster issued a forecast of the day's weather. This forecast was issued the following morning, and were, in some cases, the growers that the ordinary frost prediction was not to be taken as a basis for frost without indicating the possibility of a severe frost being necessary to combat.

During the winter the district forecaster was assisted by mail and by telephone. The district forecaster was assisted by mail and by telephone. By an arrangement with the district forecaster the Weather Bureau was given the exclusive right to use the district forecaster's office for the winter. The weather were being distributed by the district forecaster with the observer, and as soon as the district forecaster was notified in this way it required but a few minutes to get the district forecaster's forecast of the growers on the frost-forecasting service. The district forecaster was sometimes suggested, however, to use the district forecaster's office for the winter and by the operator of the district forecaster.

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and cherries from 15 to 25 per cent, including both protected and unprotected orchards. It also shows a rather surprising situation as to the damage done, in that in a number of protected or heated orchards there will be few, if any, peaches and no cherries, while in some unprotected orchards there will be this year's average of both peaches and cherries.

The active work of the Weather Bureau during this frost campaign was eminently satisfactory and pleasing to the growers. All growers who were prepared in any way to protect their orchards were kept informed as to the current weather conditions and were amply warned of the approach of all the damaging temperatures that occurred. It is stated by competent authority that the work of the bureau in conjunction with that of the growers who heated their orchards has saved a quarter of a million dollars to the fruit industry in this valley this year.

From April 1 to May 15 observations were taken at the "key" stations and at the local Weather Bureau station at 5 p. m. daily and telegraphed to the district center at Portland, Oreg. In addition to these, special observations were taken daily at this station shortly after sunset. These consisted of the pressure, current temperature, dew point, direction and velocity of the wind, and the state of the weather. The object of these special observations was to discover, if possible, some relation between the dew point in the evening and the lowest temperature on the following morning. It was found that between these two quantities there existed no definite relation that could be relied upon to determine in the evening what the minimum temperature would be on the following morning.

The value to the fruit grower of an accurate forecast of the coming minimum temperature is obviously great, even if it is not given more than six or eight hours in advance. This fact led to a study of the radiation at this station in addition to the other observations during the frost period. It was found that in fair weather such as is favorable for frost and also for uninterrupted radiation the fall in temperature from the time of the maximum during the day to 10 p. m. was very nearly twice as much as it was from 10 p. m. to the time of the minimum on the following morning. For example, if the maximum during the day was 60° and the current temperature at 10 p. m. was 40°, the minimum on the following morning would be 30°. This relation was found to exist without material deviation at any time, particularly during the latter part of March and the early part of April, and seemed to be independent of the atmospheric pressure or of the maximum day temperature. This seems to suggest the possibility of developing a method from study of the radiation by which it will be possible to inform the growers by, say, 8 p. m. or 9 p. m. exactly what the minimum temperature will be on the following morning.

There are now between 3,000 and 4,000 acres of developed orchards in the Lewiston-Clarkston district. The planting of new orchards is going on; some hundreds of acres of orchards will come into bearing next year and the increase will continue at the rate of about 1,000 acres a year until eventually there will be something in excess of 20,000 acres in orchards in the territory contiguous to Lewiston. There will be a marked increase in the practice of orchard heating in the frost season during the next few years, and there will naturally follow a corresponding increase in the importance of the Weather Bureau to the orchardists.

It does not require a close study of the foregoing reports to become aware of the importance of frost forecasts and the complexity of the problem of making them in this part of the country. As before stated, the orchardists want to know just how cold it is going to get

in their orchard and they want this information as far ahead of the time of occurrence as possible. We know that the temperature may vary as much as 8° or 10° in orchards a few miles apart and that it is not considered necessary to protect an orchard during the blooming period unless the minimum temperature goes below 29°.

Each locality has a different environment, and owing to mountain and valley breezes needs special treatment, which is evidently beyond the capability of one man to give to all the places. The plan adopted therefore is to have the district forecast amplified by a trained scientist on the ground. This is the system in operation in handling the daily forecasts of weather and temperature at all important stations of the Weather Bureau, and it is the only way to insure good work in the making and disseminating of frost forecasts in this district.

It will be noticed from the reports of the local men that data from nine new stations, viz, five in the Yakima Valley, two in the Lewiston district, one in the Boise district, and one from Medford, Oreg., were obtained during the spring of 1911 for study purposes. At a few of these stations thermograph traces were also secured. It is now proposed to analyze these data from the forecaster's standpoint to see if it is not possible to arrive at facts which will be helpful in making frost forecasts.

In 1882 Lieut. (now Brig. Gen.) James Allen published a small memoir entitled "To Foretell Frost by the Determination of the Dew Point." It is claimed in this publication that if the dew point is above freezing in the early evening the minimum temperature the next morning will be above freezing, and vice versa if the dew point is below freezing the minimum the next morning will be below that mark. The inference to be drawn from this publication, as well as from others that preceded it, is that it is an easy matter to predict frost when the dew point is known. However, meteorologists¹ since then have generally reached the conclusion that the dew point of the previous evening does not give much, if any, indication regarding the minimum temperature the next morning.

Our investigations, however, rather infer that in some places the dew point is of value in this work, and Mr. O'Gara and Mr. Wells both rely on it to a certain extent in making their local forecasts of frost. Mr. O'Gara as far back as 1908 discovered a relationship between the dew point of the previous evening and the minimum temperature the next morning, and in the *Monthly Weather Review* for September, 1910, he stated:

There is a relation existing between the dew-point temperature observed in the early evening and the minimum temperature of the following morning. For the Rogue River Valley it has been found that when the atmospheric tempera-

¹ Moore's Descriptive Meteorology, p. 114.

ture in the early evening is between 50° and 60° F. the dew-point temperature may be relied upon generally to indicate the minimum morning temperature. It has been found that for such atmospheric temperature, with clear sky and northerly winds, the minimum temperature to be expected is 3° or 4° below the dew-point temperature as observed. If the daily temperatures have been high and the winds are from the west or westerly quarters, the minimum temperature will always be higher than the observed dew point. Again, during the latter part of the spring season with long days and a very large amount of insolation the minimum temperature usually remains the same as the dew point, or even higher, depending upon the maximum temperature during the day.

An accurate record was kept during the spring of 1911 of the dew point at Boise, North Yakima, and Medford. These dew-point observations were taken on the ground with a sling psychrometer of standard make, the first observation at about 4.30 p. m., Pacific time, and it was followed by others at irregular hours, except no second observation was taken on a few nights when the conditions were markedly unfavorable for the formation of frost. For the month of April the averages were as given in Table II.

TABLE II.—*Dew point and minimum temperature readings, month of April 1911.*

Stations.	Dew point, 4.30 p. m.	Morning minimum temper- ature.	Difference.
Medford.....	34.7	34.8	+ 0.1
North Yakima.....	22.7	36.8	+14.1
Boise.....	26.7	33.5	+ 6.8

In Table II we see the average dew point at about 4.30 p. m. and the average minimum temperature on the following morning agree very closely at Medford, while at North Yakima and Boise there are marked differences. If the differences were constant the problem of predicting exact minimum temperatures would be an easy matter, but instead there are decided variations from day to day. At Medford the range was from +12 to -8, at North Yakima from +30 to -8, and at Boise from +18 to -6. These differences were obtained from the records for the entire month, during which time all sorts of weather prevailed. If we only take dew-point observations that are followed by freezing temperatures we cut these ranges down considerably at Medford and North Yakima, but no change is effected at Boise. The reduction is from the positive side in all cases, as the negative side remains the same. The ranges with this elimination are still too great to be helpful in judging what the minimum temperature will be unless they can be still further reduced through correlations with different phases of weather, and an attempt has been made to do this with the following results:

TABLE III.—Record of observations at Medford, Oregon, from Apr. 1, 1910, to Apr. 30, 1910, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		State of weather.	Wind.		Minimum temperature (last morning).	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.		Direction.	Force (estimated).		
1	6.45 p. m.			52.0	45.0	Cloudy.	nw.	Brisk.	36	Cloudy at 3 a. m. Firing general.
2	1.15 a. m.			50.0	40.0	Clear.	nw.	High.		
2	7 p. m.			47.0	40.0	Cloudy.	w.	Brisk.	26	
2	10 p. m.			41.0	36.5	Clear.	w.	Light.		
3	6.30 p. m.			55.0	43.0	do.	nw.	Slight.		Firing general on valley floor.
3	8			47.0	40.0	do.	s.	do.		Unsmoked orchards badly hurt.
3	10			44.0	38.0	do.	se.	do.	27	
4	6.30			43.0	38.0	do.	s.	do.		
4	8.15			56.0	48.5	do.	n.	Slight.	39	
5	6.45			52.0	47.0	do.	n.	Light.	34	
5	11.15			50.0	45.0	Hazy.	nw.	Brisk.		
6	6.30			55.0	44.0	do.	nw.	do.		Clouded again about 3 a. m., Apr. 7
6	9			51.0	42.0	Clear.	ne.	Slight.	31	Only 1° of frost. No firing.
7	6.35			50.0	47.0	Partly cloudy.	nw.	Moderate.		
7	10.30			57.5	45.0	do.	nw.	do.	31	
8	6.45			50.0	48.0	Cloudy.	nw.	do.	32	
9	6.35			50.0	51.0	do.	ne.	Slight.	44	
10	6.35			56.0	46.5	Partly cloudy.	se.	Strong.		Thermometer just reached 32°. No frost.
10	9.45			54.0	45.0	Clear.	se.	Brisk.	32	
11	6.45			57.0	49.0	Partly cloudy.	nw.	Light.	40	
12	6.40			50.0	50.0	do.	ne.	Slight.		
12	7.45			56.0	49.0	Clearing.	ne.	do.	40	
13	6.40			52.0	42.0	Clear.	ne.	Brisk.		Firing general. Some orchard temperatures raised 10°.
13	11.45			41.0	36.5	do.	e.	Slight.	26	
14	6.30			64.0	48.0	Partly hazy.	s.	Slight.	31	No firing done.
14	11.30			45.0	39.5	Clear.	w.	do.		
15	6.45			70.0	62.5	do.	s.	Brisk.	31	
15	11			53.0	44.5	do.	s.	do.		
16	6.40			71.0	56.0	Hazy.	n.	Light.	40	
17	6.45			76.0	57.0	do.	n.	do.	38	
18	6.45			74.0	58.0	do.	n.	do.	42	
19	6.45			81.0	49.0	Raining.	w.	Slight.	40	
20	6.40			61.0	51.0	Clear.	se.	do.	39	
20	10.30			49.0	46.0	do.	sw.	do.	37	
21	6.45			69.0	55.0	Hazy.	sw.	do.	45	
22	6.50			74.0	59.0	Clear.	sw.	do.	40	
23	6.45			79.0	57.0	do.	s.	do.		

24	6.45	80.0	80.0	45	Few clouds	nw.	do	44
25	6.30	58.0	49.5	42	Hazy	nw.	High	44
26	6.45	58.0	47.0	35	Clear	ne.	Strong	
27	10.15	48.0	47.0	35	Clear	do	Strong	33
28	6.40	59.0	49.5	40	Raining	ne.	Strong	40
29	6.45	60.0	46.0	29	Clear	ne.	Light	
30	6.45	45.0	40.0	34	do	do	do	36
31	28	10	48.0	46	Raining	w.	Slight	45
32	6.45	58.0	47.0	36	Partly cloudy	nw.	Brisk	
33	5.35	58.0	47.5	39	do	do	do	
34	6.30	64.0	47.5	40	do	nw.	do	
35	8.45	50.0	46.5	43	Raining	ne.	Slight	37

TABLE IV.—Record of observations at Medford, Oreg., from Apr. 1, 1911, to Apr. 30, 1911, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.		Direction.	Force (estimated).		
1	5	28.00	-0.05	72.5	51.5	Clear	nw.	Brisk		Slight hoar frost on ground. Clouded between 4 a. m. and 6 a. m. Lowest temperature recorded, 30°. No firing; no damage.
1	6.30	28.00	— .05	66.0	46.0	do	nw.	Gentle	34.0	
2	5	27.90		63.0	50.0	Cloudy	ne.	do	35.0	Cleared about 8 p. m., but clouded heavily again before morning.
2	6.30	27.90		57.0	45.0	do	ne.	do		
3	5	28.00		53.0	44.5	do	ne.	Brisk		
3	6.30	28.02		52.0	44.0	do	ne.	do	37.0	Rain began about 3 a. m.
4	5	28.00		41.0	39.0	Raining	nw.	Gentle		
4	6.30	28.00		40.5	30.0	do	nw.	do	35.0	
5	5	28.00		53.0	48.0	Cloudy	nw.	do		
5	6.30	28.00		51.0	46.0	do			39.5	
5	8.30	28.05	+ .05	44.0	42.0	Partly cloudy	n.	Gentle		Light frost. Temperature ranged from 29° to 31° over valley. Unfired tracts not injured.
6	5	28.15		60.0	49.0	do	nw.	Very gentle	30.0	
7	5	29.74	- .05	67.0	53.0	do	nw.	do		
7	6.30	29.74		60.0	52.0	do	nw.	do		Wind blew briskly from all quarters after 8 p. m., but principally from south and southeast.
7	8.45	29.74		53.0	48.0	do	nw.	Brisk	35.0	At 9 p. m. sky cleared and temperature fell rapidly. Had the sky remained clear freezing temperatures would have occurred.
8	5	29.49	- .01	58.0	48.0	Cloudy	n.	Gentle		Clouded in early morning.
8	6.30	29.54	+ .05	56.0	47.0	do	sw.	Brisk		
8	8.45	29.54	+ .05	49.0	44.0	Clearing	sw.	Gentle	36.0	
9	5	29.69	+ .05	51.0	40.0	Partly cloudy	w.	Brisk		
9	6.30	29.74	+ .05	45.0	41.0	do	w.	do	36.0	
9	9.45	29.79	+ .05	42.0	39.0	do	w.	do		
10	5	29.79		41.0	38.0	Rain	w.	Gentle	31.5	Clouds, rain, snow.
11	5	29.94		41.0	37.0	Partly cloudy	nw.	Brisk		Clouds prevailed most of night. Lowest temperature, 24°. Fired in few spots where temperature below 29° occurred.
11	6.30	30.24	+ .05	34.5	39.0	do	w.	do	29.5	Clouds prevailed till 4.30 a. m. Sky cleared and temperature went to 27° in greater part of valley. Lowest recorded, 25°.
12	5	28.40		40.5	37.0	do	ne.	do		
12	6.30	28.40		37.5	35.5	Raining	ne.	Gentle	27.5	Wind strong from southerly and westerly quarters till 5 a. m. Changed, and sudden drop of temperature. Lowest recorded, 22°. General, 23° to 25°.
13	5	28.45		54.0	41.5	Clear	n.	do		
13	6.30	28.45		50.5	39.0	do	se.	Brisk	25.0	Wind strong from south all day. Changed to north after 8.30 p. m.
14	5	28.40	- .05	66.0	47.5	do	se.	do		Reached 32° at 2 a. m. Temperature reported, 22-25° over valley.
14	6.30	28.40		61.0	45.0	do	se.	Gentle		Unmudged tracts badly damaged.
14	Midnight	28.45		38.0	34.0	do	nw.	do	25.0	

15	5	28.30	70.0	52.0	33.0	do	nw.	Brisk	Remained clouded all night, with northerly winds.
15	6.30	28.30	64.0	46.0	28.0	Partly cloudy	nw.	Gentle	
15	8	28.30	53.0	48.0	28.0	do	nw.	do	
16	Noon	28.35	62.0	51.0	40.0	Clear	nw.	Brisk	
16	5	28.30	64.0	51.0	38.0	do	nw.	do	
16	6.30	28.30	68.0	47.0	35.0	do	nw.	Gentle	Temperature of 30° over valley, generally over valley. Firing not necessary.
16	10	28.22	43.5	39.5	35.0	do	nw.	Very gentle	
17	5	28.15	71.0	51.0	28.0	Partly cloudy	ne.	do	Clouds all night.
17	6.30	28.10	62.5	49.5	35.5	Cloudy	ne.	do	
17	9.30	28.10	58.0	47.0	35.0	do	ne.	do	Mostly clouded over key station at Medford. Temperatures of 24° to 26° recorded in north end of valley. Few fires. Upper end of valley remained clouded most of night.
18	5	28.40	52.0	43.0	32.0	Partly cloudy	nw.	Brisk	
18	6.30	28.45	48.0	39.0	26.0	Clearing	n.	do	
19	5	28.30	60.0	48.0	35.0	Clear	nw.	Gentle	
19	6.30	28.30	58.0	45.0	33.0	do	nw.	do	
20	5	28.00	72.0	56.0	41.0	do	nw.	do	Some firing.
20	6.30	28.00	67.0	53.0	40.0	do	ne.	do	
21	5	28.14	70.0	54.5	38.0	do	ne.	Brisk	Partly cloudy during morning.
21	6.30	28.15	64.0	52.0	41.0	do	n.	do	
22	5	28.17	72.0	53.5	35.0	do	ne.	Gentle	
22	6.30	28.17	66.0	53.0	41.0	do	ne.	do	
23	5	28.10	81.0	58.0	38.0	do	nw.	do	
23	6.30	28.10	73.0	56.0	41.0	do	n.	do	
24	5	27.05	80.0	60.0	44.0	Hazy	nw.	Brisk	
24	6.30	28.00	71.0	52.5	33.0	Partly cloudy	nw.	do	Cloudy most of night.
25	5	27.00	64.0	53.0	44.0	Cloudy	nw.	do	
25	6.30	27.00	57.0	48.5	41.0	do	nw.	do	Do.
26	5	27.55	50.0	45.0	40.0	do	nw.	Gentle	
26	6.30	27.55	50.0	43.5	40.0	do	ne.	do	
27	5	28.11	52.0	43.5	33.0	Partly cloudy	n.	Brisk	
27	6.30	28.15	46.5	41.0	29.0	do	ne.	do	Do.
28	5	28.25	60.0	46.5	30.0	Clear	ne.	do	22° in two places for a short time. Average over valley, 26°. Firing general.
28	6.30	28.25	54.5	44.0	31.0	do	ne.	do	Clouds came about 1 a. m. Remained clouded until early morning.
29	5	28.21	68.5	51.0	32.0	do	ne.	do	
29	6.30	28.25	64.0	49.0	32.0	do	nw.	Gentle	
30	5	28.05	63.0	53.0	41.0	Raining	nw.	do	
30	6.30	28.05	62.0	52.0	43.0	Partly cloudy	nw.	do	Cloudy all night with trace of rain.

At Medford (see Tables III and IV) the conclusions reached after a careful analysis of the observations taken in April, 1910 and 1911, are as follows: The 5 p. m. dew-point observations show nearly as close an agreement with the minimum temperatures as do the dew-point readings obtained later in the day. The dew point more nearly agrees with the minimum temperature the next morning when the weather is cloudy at the time of the observation, and it is farthest from the minimum temperature when the weather is partly cloudy. Both the average difference and the range are least with cloudy weather and greatest with partly cloudy weather.

The winds are nearly always from the northeast or northwest on evenings with freezing temperatures, and they are usually from one or the other of these directions when no freezing temperatures occur. There is apparently just as wide a variation between the dew point and the minimum temperature when the winds are calm as there is when they are light, gentle, or brisk. On frosty nights the difference between the evening dew point and the minimum temperature the next morning is greatest when the pressure gradients are medium or steep and least when they are weak; when weak, frost seldom occurs. Frosts form oftenest when the barometer at Marshfield is about 30.3 inches (sea level) or above; on one occasion frost formed when the barometer at Marshfield the preceding evening was as low as 29.6 inches. It makes little difference regarding the height of the barometer as to the difference between the dew point and the minimum temperature, although the tendency is for a greater difference the higher the barometer reads.

The position of the highs and lows furnishes the best information in connection with the relationship of the evening dew point with the minimum temperature the next morning. When the high is in the northwest and the low in the southeast, the difference will be greatest and average 5.6° below the dew point; when the low is in the east and the high in the west, the difference will average -3.3° ; when the low is in the northeast and the high in the southwest (moving up the coast), the difference will average -2.4° ; when the high is inland and the low off the California coast, the difference will average $+1^{\circ}$, and when the high is in the north and the low in the south, the average will also be $+1^{\circ}$.

The application of the foregoing factors will approximate the minimum temperatures within 1° in all cases, except when the high is in the northwest and the low in the southeast, and then the approximation will be within $2\frac{1}{2}^{\circ}$, which is sufficiently close to be of value in determining the question of "how cold it will be." More observations will probably enable us to make other correlations that will be helpful, and it is probable that we will find some "freaks"

as our record lengthens that will need further study to properly classify.

During the two seasons there were nine cases with the dew point above 32 that were followed by freezing temperatures. In none of these cases was the minimum temperature low enough to make it necessary to start fires in the orchards, the lowest being 29.5° on April 19, 1911. The temperatures that occurred were what would be expected by using the factors for position of the highs and lows, and they were really "near cases" that are easily handled.

In 6 cases frost did not occur when the evening dew point was below 32, and these cases are puzzling. Cloudiness which prevented radiation was the cause of the absence of frost with these low dew points, but no hard and fast rule can be found to assist in predicting whether or not cloudiness will or will not prevail during the night. If the barometer is low, that alone favors cloudiness, and if high and the surrounding country is cloudy and movement sluggish, as indicated by the behavior of the barometer at stations in the vicinity, clouds will probably continue.

TABLE V.—Record of observations at North Yakima, Wash., from Apr. 1, 1911, to Apr. 30, 1911, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.		Direction.	Force (estimated).		
1	4.10.	28.53	+0.03	63.0	44.5	ne.	ne.	10.	...	Strong southwest to west wind all day.
1	6.40.	28.60	+0.06	49.0	39.0	ne.	ne.	8.	...	Wind in puffs during evening.
1	8.50.	28.67	+0.06	46.0	37.0	n.	n.	Light.	...	Wind in puffs.
2	1.10.	28.70	+0.03	44.8	36.3	n.	n.	do.	35	Very light wind; almost none.
2	4.15.	28.66	-0.03	53.7	39.0	e.	e.	do.	...	Clouds thinned out till sky was almost clear between 7.30 and 9.30 p. m. At 9 they were still quite thin.
2	6.45.	28.64	-0.01	48.2	36.2	ne.	ne.	do.	...	
2	9.00.	28.65	+0.01	45.8	35.1	ne.	ne.	do.	37	
3	4.20.	28.54	(-)	50.0	41.0	do.	do.	6.	...	Cloudy all day.
3	6.40.	28.55	(+)	44.2	38.7	9 a. st., few s. cu.	n.	Light.	...	Sky was clear all night up to about 2 or 3 a. m.; after that it clouded over and prevented a freeze which would otherwise have occurred.
3	8.50.	28.56	+0.01	41.8	37.3	Few cl. st.	n.	do.	...	
3	11.00.	28.56	(-)	38.5	35.0	Few a. st.	n.	do.	34	
4	4.20.	28.64	(-)	48.5	42.5	3 st. cu.	n.	6.	...	
4	6.50.	28.63	+0.01	45.0	36.3	4 st. cu.	n.	6.	...	Wind in light puffs from north.
5	4.20.	28.66	+0.01	40.0	33.2	Few cl. st.	n.	Light.	28	Clear all day and light southeast air.
5	6.50.	28.67	(-)	52.0	38.2	Few cl. cu.	se.	do.	...	Few cl. moving at tremendous speed from northwest.
5	9.20.	28.70	+0.03	47.4	36.0	4 cl.	w.	do.	...	Surface drift of air family discernible from south. Halo at 9 p. m.; cl. and cl. st. moving swiftly from northwest.
5	11.00.	28.69	-0.01	37.5	33.8	7 cl. st.	s.	do.	25	Cl. st. clouds moving from northwest. Cleared off at 11.30 and stayed clear all night.
6	4.20.	28.80	+0.06	57.5	43.0	...	n.	6.	...	Brisk north wind during day.
6	6.55.	28.83	+0.04	48.8	38.2	...	n.	8.	...	Bank of st. cu. clouds low in northwest.
6	8.50.	28.87	+0.04	46.2	37.2	...	n.	5.	...	Wind blew about 4 to 6 miles per hour through night, sufficiently to almost jeopardize the forecast.
6	11.00.	28.90	+0.03	43.0	...	...	n.	30	...	Scarcely any motion to air.
7	4.20.	28.86	-0.04	61.0	45.0	...	s.	Light.	...	Calm and clear all night.
7	7.00.	28.84	-0.01	54.8	41.3	...	sw.	do.	30	
7	9.00.	28.80	-0.04	46.8	36.8	...	sw.	do.	...	
8	4.20.	28.44	-0.08	69.0	49.0	3 cl., 2 cl. st., 2 cu.	se.	Light.	...	
8	6.50.	28.40	-0.04	62.7	48.0	10 st. cu.	w.	do.	45	
9	4.20.	28.47	-0.02	55.0	44.5	2 cl. st., 8 st. cu.	sw.	16.	...	
9	7.00.	28.51	+0.03	50.0	43.0	4 a. cu., 3 st. cu.	sw.	10.	...	Clear and calm for a large part of night. Sky became overcast by morning, preventing a freeze.
9	9.00.	28.57	+0.06	46.8	40.5	4 st. cu.	sw.	...	39	
10	4.20.	28.60	-0.02	46.0	38.8	10 cu.	s.	6.	...	Cloudy all day with trace of rain in afternoon.
10	6.50.	28.60	+0.02	43.0	33.3	3 cu.	sw.	8.	...	Southwest wind 3 to 6 miles blew all night. Some cloudiness.
10	9.00.	28.65	+0.05	37.0	31.0	Few cu.	sw.	6.	29	0.01 inch of snow in afternoon.
11	4.20.	28.73	+0.01	47.0	35.8	5 cu., 5 st. cu.	nw.	10.	...	Northwest wind greater part of night and occasional cloudiness.
11	7.00.	28.75	(+)	41.0	32.0	7 st. cu.	nw.	10.	26	

12	4.20	28.95	(+)	45.0	33.0	8	7 cu.	nw.	5	.....	Cloudy all day and fresh north wind.
12	7	28.98	+ .03	40.0	30.3	10	Few cu.	nw.	8	.....	
12	9.45	29.05	+ .05	36.7	30.2	19	.....	nw.	6	.....	
13	4.30	29.16	(+)	54.6	38.6	10	.....	nw.	24	.....	Clear all day with gentle south to southeast wind.
13	7	29.20	+ .04	57.0	37.0	22	.....	nw.	3	.....	
13	4.20	29.24	+ .02	49.0	42.0	18	.....	se.	25	.....	Clear all day.
14	7	29.26	- .01	53.5	39.0	15	Few cl. st.	se.	.....	.....	
14	9.30	29.28	- .01	42.7	33.0	18	.....	se.	.....	.....	
15	4.20	28.98	- .08	68.0	46.2	14	Few cl., 1 cl. st., 3 a. st.	s.	.....	.....	Clear nearly all day, cloudiness commencing about mid-afternoon.
15	7	28.90	- .04	59.0	43.3	21	10 a. st.	s.	.....	.....	
15	9.30	28.90	(+)	56.4	41.8	21	Overcast.	s.	.....	.....	
16	4.20	28.98	- .02	59.0	43.3	21	.....	nw.	.....	.....	
16	7	28.97	+ .02	49.6	39.6	28	Few cl. st., few cu.	nw.	10	.....	
16	9.30	29.01	+ .07	45.7	36.5	28	.....	nw.	8	.....	
17	4.20	28.88	- .07	60.8	44.3	22	10 a. st.	sw.	.....	.....	Sky overcast major part of day; about 25 per cent of sunshine.
17	7	28.81	- .04	56.3	42.3	23	.....	nw.	5	.....	
17	4.20	28.82	- .06	53.0	40.5	123	Few cu.	nw.	14	.....	
18	7	28.98	+ .06	43.3	37.0	28	Few st. cu.	nw.	10	.....	Wind during night prevented freeze.
18	9	29.05	+ .02	42.5	36.8	28	.....	nw.	20	.....	
19	4.20	29.08	- .02	64.0	46.7	25	3 cl. st.	ne.	6	.....	Shortly after 7 p. m. the wind increased to about 10 or 12 miles per hour, subsiding shortly after 8 o'clock. Increased after 9.30 p. m. and blew at intervals through night.
19	7	29.10	+ .01	54.7	43.0	28	.....	nw.	6	.....	
19	9	29.13	+ .03	50.0	40.5	28	.....	nw.	.....	.....	
19	10.45	29.10	- .07	48.3	39.5	28	.....	nw.	8	.....	
20	4.20	28.70	- .07	72.0	51.5	29	.....	nw.	.....	.....	
20	7	28.71	- .04	65.3	40.0	31	.....	nw.	.....	.....	
20	9	28.73	+ .02	56.0	44.4	31	.....	ne.	.....	.....	
21	4.20	28.73	+ .02	71.0	53.2	36	7 st. cu.	ne.	.....	.....	Very little motion to air.
21	7	28.82	+ .06	59.4	47.0	36	.....	nw.	8	.....	
21	10.45	28.88	+ .01	52.0	44.2	35	.....	nw.	6	.....	
22	4.20	28.93	- .01	68.0	49.7	32	Few cu.	ne.	.....	.....	
22	7	28.98	+ .02	64.0	48.7	32	.....	ne.	.....	.....	
22	9.25	28.98	- .02	57.0	45.8	33	.....	nw.	.....	.....	
22	4.20	28.85	- .04	74.7	53.8	33	.....	s.	.....	.....	Do.
23	7	28.85	- .07	67.3	51.2	34	.....	sw.	.....	.....	Do.
23	9.15	28.86	- .01	56.8	45.8	34	Few cl., few cu.	sw.	.....	.....	Wind in puffs; scarcely any at times.
24	4.20	28.57	+ .06	81.0	55.3	29	Few cl., few cl. st., few cu.	w.	.....	.....	
24	7	28.58	- .03	70.7	53.2	36	.....	nw.	.....	.....	
24	9	28.60	+ .02	62.8	50.0	37	.....	nw.	.....	.....	
25	4.20	28.65	- .03	60.0	43.8	37	4 cl. st.	nw.	6	.....	
25	7	28.65	- .03	52.0	39.7	21	3 cl. st.	nw.	10	.....	
25	9	28.68	+ .03	49.0	37.2	18	.....	nw.	5	.....	
25	11	28.67	- .01	46.1	36.2	21	.....	nw.	.....	.....	
26	4.20	28.44	- .04	63.8	44.3	14	3 cl. st.	se.	.....	.....	Very little motion to air.
26	7	28.44	- .01	60.8	44.2	21	4 a. st.	nw.	.....	.....	
26	10.45	28.50	+ .06	51.8	41.0	27	.....	nw.	.....	.....	
27	4.20	28.63	+ .04	63.0	46.8	25	Few cl., few cl. st.	nw.	18	.....	Wind commenced about 3 p. m. Calm at Sunnyside at 4.30 p. m.
27	7	28.71	+ .04	53.5	41.3	24	Few cl. st.	nw.	14	.....	
27	8	28.75	+ .04	52.0	40.0	23	.....	nw.	18	.....	

Frost seldom forms at North Yakima (see Table V), as the dew-point is usually far below the freezing point. The dew-point observations taken at 7 p. m. show a closer relationship to the minimum temperature the next morning than do those taken at 4.20 p. m. For the month of April the differences averaged 14.6 at 4.20 p. m. and 12.2 at 7 p. m. For mornings followed by freezing temperatures these differences were 9 at both the 4.20 p. m. and the 7 p. m. observations. The ranges are large, being for the month from -8 to $+30$ at 4.20 p. m., and from $+3$ to $+23$ at 7 p. m. On mornings followed by freezing temperatures they were from -8 to $+16$ at 4.20 p. m. and from $+3$ to $+14$ at 7 p. m. There is a strong probability that the dew-point observation taken at 4.20 p. m. on the 4th is in error, as it is the only date during the series when the following temperature sank below the dew-point, and the observation taken at 7 p. m. on that date gave a dew-point 13 points lower, thus making the minimum temperature 5° higher instead of 8° lower, as computed from the 4.20 p. m. observational data. If we exclude this apparently erroneous reading, we get a range on frosty mornings from the 4.20 p. m. observation from 0 to $+16$, which, as will be seen, is 5° greater than that obtained from the observations taken at 7 p. m.

It seems to make no difference at North Yakima whether the weather is clear or cloudy when the dew-point observation is taken as to the variations in the range between that point and the minimum temperature the next morning. When clear the average difference for 18 observations was 13.3, and when cloudy for 7 observations it was 12.6. On partly cloudy evenings the average was 19. There were five mornings with freezing temperatures when the winds during the preceding evening were from the southeast or south and four when they were from the north or northwest. There were many other evenings with the same directions that were not followed by freezing temperatures.

The differences between the evening dew point and the following minimum temperature were practically the same, no matter what direction the wind blew from or whether or not the pressure gradients were for light or strong winds. No freezing temperatures followed those evenings when the winds were brisk, but when they were light there were four and when moderate there were five mornings with freezing temperature. The dew point at North Yakima averaged 22.7 at 4.20 p. m. and 24.6 at 7 p. m., but when above 32 at either of these hours no frost need be expected, which is contrary to the conditions in the Rogue River Valley, where there were nine days in two years with the dew-point above 32 that were followed by freezing temperatures. Freezing temperatures occur at all heights of the barometer, beginning with readings as low as 29.80 inches up to 30.50

inches or more. Owing to the uncertainty in the temperature factor used in reducing barometer readings to sea level at the altitude of North Yakima the isobars sometimes appear to be misplaced, and very little weight can be given to the fact of their being crowded together or wide apart when making frost forecasts for this station.

When the high is in the southwest (moving up the coast) and the low in the northeast, the dew-point will be from 0 to 9° lower than the minimum temperature the next morning; when the high is in the west and the low in the east, the dew point will be from 7° to 16° lower; when the high is in the northwest and the low in the southeast, these differences will range from 10° to 15°; and when the high is in the east and the low in the west the difference was 15° on the only occasion when this situation occurred.

The lowest dew-point at 4.20 p. m. that was followed by freezing temperature was 8, and the lowest at 7 p. m. was 10, while the highest (excluding the apparently erroneous observation on the 4th) were 29 and 23, respectively. These factors show variations too large to be of much value in placing the minimum temperatures at North Yakima, but they are helpful when taken in consideration with other conditions, and it is believed the dew-point observations should be continued at this station as well as at Medford. It is worthy of note that when the gradients were steep at North Yakima and freezing temperatures occurred, the high was in the southwest and the low in the northeast, and radiation played but a small part in cooling the air, but instead genuine freezes occurred with a great deal of cloudiness.

TABLE VI.—Record of observations at Boise, Idaho, from Apr. 1, 1911, to Apr. 30, 1911, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.			Direction.	Force (estimated).		
1.	5.15.	26.88	-.05	69.8	46.9	18	Clear.	n.	10	35	Sky clouded during night.
2.	5.15.	26.88	-.05	68.6	41.0	15	Cloudy.	w.	4	35	Partly cloudy to cloudy during night.
3.	7.	26.86	-.04	57.7	41.4	19	do.	w.	2	42	Do.
4.	5.20.	26.84	-.03	56.8	42.1	25	do.	nw.	5	33	Do.
5.	5.20.	26.84	-.03	56.8	42.1	25	Light rain.	ne.	3	33	Cloudy all night.
6.	5.20.	26.97	-.01	43.4	39.4	36	Clear.	nw.	14	26	Clear all night.
7.	5.20.	26.90	-.02	48.2	38.5	19	do.	nw.	4	28	Do.
8.	5.20.	27.05	-.02	53.2	42.3	29	do.	nw.	4	33	Chinook began during night.
9.	5.20.	27.25	-.01	56.7	40.6	18	do.	sw.	4	33	Do.
10.	7.50.	27.25	-.01	48.2	37.9	34	do.	e.	2	47	Rapidly falling barometer.
11.	5.20.	26.99	-.02	61.2	47.8	34	Light rain.	se.	8	35	Thunderstorm in afternoon.
12.	5.20.	26.95	-.01	54.0	43.5	32	do.	w.	8	34	Cloudy most of night.
13.	5.15.	27.05	-.05	51.8	40.8	28	Cloudy.	ne.	3	24	Cloudy to midnight; clear to partly cloudy midnight to 2.20 a. m. of 12th; cloudy thereafter.
14.	5.20.	27.10	-.05	34.5	32.0	28	Light snow.	w.	10	24	Generally cloudy all night, 12th-13th.
15.	8.	27.09	-.04	33.1	30.9	28	Cloudy.	se.	4	24	Clear all night.
16.	5.25.	27.23	+.02	33.3	30.2	26	do.	n.	12	20	Do.
17.	8.15.	27.26	+.02	32.0	29.3	25	do.	n.	2	21	Do.
18.	8.15.	27.45	+.03	44.1	32.4	11	Clear.	n.	6	26	Do.
19.	8.15.	27.47	+.03	38.1	32.7	26	do.	nw.	2	31	Do.
20.	10.	27.52	-.02	35.6	29.1	18	do.	n.	3	26	Do.
21.	5.20.	27.60	-.02	50.9	36.0	10	do.	s.	4	31	Do.
22.	8.	27.61	-.07	60.4	41.5	13	do.	nw.	9	28	Do.
23.	5.20.	27.43	-.05	53.8	45.0	22	do.	se.	9	38	Chinook conditions in night.
24.	8.20.	27.13	-.05	53.8	45.0	22	do.	n.	4	38	Snow and rain during night.
25.	5.20.	27.19	-.04	59.2	42.3	20	do.	w.	9	37	Cloudy all night.
26.	7.45.	27.17	-.02	51.3	38.8	22	Light snow.	n.	3	30	Clear part of night.
27.	5.20.	27.15	+.16	35.6	34.7	34	do.	nw.	14	33	Clear all night.
28.	5.20.	27.26	-.03	41.4	41.7	30	Cloudy.	ne.	6	33	Clear all night.
29.	5.20.	27.24	-.03	40.6	40.6	35	Partly cloudy.	se.	5	30	Clear all night.
30.	5.20.	27.23	-.02	55.9	43.2	28	do.	s.	3	33	Do.
31.	5.20.	27.23	-.01	50.7	42.3	33	do.	se.	2	37	Do.
32.	8.	27.23	+.01	60.7	42.3	33	Clear.	n.	8	40	Chinook conditions during night.
33.	5.15.	27.21	+.02	66.4	49.6	33	do.	n.	3	49	Generally cloudy all night.
34.	8.15.	27.23	+.03	57.6	47.7	38	do.	n.	7	45	Cloudy and rainy all night.
35.	5.20.	27.24	-.02	68.2	51.3	36	do.	ne.	4	42	Cloudy and damp all night.
36.	5.20.	27.08	-.04	71.6	51.1	31	Partly cloudy.	n.	6	36	Cloudy all night.
37.	5.15.	26.86	-.02	65.1	50.0	36	Cloudy.	nw.	7	35	Partly cloudy to clear during night.
38.	5.15.	26.71	-.03	47.3	42.8	41	do.	n.	10	44	Chinook conditions at night.
39.	5.15.	26.97	+.01	50.4	45.9	41	do.	n.	4	44	
40.	8.20.	27.16	+.01	59.4	47.5	36	Partly cloudy.	se.	3	44	
41.	5.15.	27.22	-.03	61.3	44.6	37	do.	nw.	2	44	
42.	5.15.	27.13	-.01	54.1	44.6	34	Clear.	sw.	2	44	

On account of elevation the danger of frost in the Boise district (see Table VI) extends over a longer period than at either of the other places which have been considered. During the spring of 1911 there were 10 mornings in April with the temperature 32° or lower and 3 in May. The May frosts were not heavy, and that our comparison may cover the same period in all three districts only those for April have been considered in this discussion.

Regular dew-point observations were taken at 4.20 p. m., Pacific time, and quite a number were taken at about 7 p. m., but there were not enough of the latter to definitely determine its advantages as compared with the earlier observation. Mr. Wells, the official in charge of the Boise station, states in his report that "the 8 p. m. (7 p. m. Pacific time) dew-point on the lawn forms an excellent indication of the expected minimum temperature near the ground when there is no convection together with the relative humidity and other local conditions"; also, "that the 5.20 p. m. (4.20 p. m. Pacific time) reading made before taking the regular observation is usually the best results in the spring." Mr. Wells thinks when the dew-point is high the minimum temperature is usually below and when it is low it is above the dew-point of the previous evening. "The same rule works with the dew-point when it is high in the morning and the minimum is below and when low it is above, and the lower the dew-point the higher above the minimum temperature will be." He also states to see no objection in bringing the humidity into the forecast, but the only way to do so is for the same purpose.

The average dew-point in Boise is 44° F. for the month of April, and the difference between the minimum temperature the next morning and the dew-point is 10.5° F. The same is true of the differences between the minimum temperature and the dew-point in greater than 6.8, 6.9, 7.0, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8.0, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9.0, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 10.0, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 11.0, 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9, 12.0, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13.0, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 14.0, 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 15.0, 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 16.0, 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 17.0, 17.1, 17.2, 17.3, 17.4, 17.5, 17.6, 17.7, 17.8, 17.9, 18.0, 18.1, 18.2, 18.3, 18.4, 18.5, 18.6, 18.7, 18.8, 18.9, 19.0, 19.1, 19.2, 19.3, 19.4, 19.5, 19.6, 19.7, 19.8, 19.9, 20.0, 20.1, 20.2, 20.3, 20.4, 20.5, 20.6, 20.7, 20.8, 20.9, 21.0, 21.1, 21.2, 21.3, 21.4, 21.5, 21.6, 21.7, 21.8, 21.9, 22.0, 22.1, 22.2, 22.3, 22.4, 22.5, 22.6, 22.7, 22.8, 22.9, 23.0, 23.1, 23.2, 23.3, 23.4, 23.5, 23.6, 23.7, 23.8, 23.9, 24.0, 24.1, 24.2, 24.3, 24.4, 24.5, 24.6, 24.7, 24.8, 24.9, 25.0, 25.1, 25.2, 25.3, 25.4, 25.5, 25.6, 25.7, 25.8, 25.9, 26.0, 26.1, 26.2, 26.3, 26.4, 26.5, 26.6, 26.7, 26.8, 26.9, 27.0, 27.1, 27.2, 27.3, 27.4, 27.5, 27.6, 27.7, 27.8, 27.9, 28.0, 28.1, 28.2, 28.3, 28.4, 28.5, 28.6, 28.7, 28.8, 28.9, 29.0, 29.1, 29.2, 29.3, 29.4, 29.5, 29.6, 29.7, 29.8, 29.9, 30.0, 30.1, 30.2, 30.3, 30.4, 30.5, 30.6, 30.7, 30.8, 30.9, 31.0, 31.1, 31.2, 31.3, 31.4, 31.5, 31.6, 31.7, 31.8, 31.9, 32.0, 32.1, 32.2, 32.3, 32.4, 32.5, 32.6, 32.7, 32.8, 32.9, 33.0, 33.1, 33.2, 33.3, 33.4, 33.5, 33.6, 33.7, 33.8, 33.9, 34.0, 34.1, 34.2, 34.3, 34.4, 34.5, 34.6, 34.7, 34.8, 34.9, 35.0, 35.1, 35.2, 35.3, 35.4, 35.5, 35.6, 35.7, 35.8, 35.9, 36.0, 36.1, 36.2, 36.3, 36.4, 36.5, 36.6, 36.7, 36.8, 36.9, 37.0, 37.1, 37.2, 37.3, 37.4, 37.5, 37.6, 37.7, 37.8, 37.9, 38.0, 38.1, 38.2, 38.3, 38.4, 38.5, 38.6, 38.7, 38.8, 38.9, 39.0, 39.1, 39.2, 39.3, 39.4, 39.5, 39.6, 39.7, 39.8, 39.9, 40.0, 40.1, 40.2, 40.3, 40.4, 40.5, 40.6, 40.7, 40.8, 40.9, 41.0, 41.1, 41.2, 41.3, 41.4, 41.5, 41.6, 41.7, 41.8, 41.9, 42.0, 42.1, 42.2, 42.3, 42.4, 42.5, 42.6, 42.7, 42.8, 42.9, 43.0, 43.1, 43.2, 43.3, 43.4, 43.5, 43.6, 43.7, 43.8, 43.9, 44.0, 44.1, 44.2, 44.3, 44.4, 44.5, 44.6, 44.7, 44.8, 44.9, 45.0, 45.1, 45.2, 45.3, 45.4, 45.5, 45.6, 45.7, 45.8, 45.9, 46.0, 46.1, 46.2, 46.3, 46.4, 46.5, 46.6, 46.7, 46.8, 46.9, 47.0, 47.1, 47.2, 47.3, 47.4, 47.5, 47.6, 47.7, 47.8, 47.9, 48.0, 48.1, 48.2, 48.3, 48.4, 48.5, 48.6, 48.7, 48.8, 48.9, 49.0, 49.1, 49.2, 49.3, 49.4, 49.5, 49.6, 49.7, 49.8, 49.9, 50.0, 50.1, 50.2, 50.3, 50.4, 50.5, 50.6, 50.7, 50.8, 50.9, 51.0, 51.1, 51.2, 51.3, 51.4, 51.5, 51.6, 51.7, 51.8, 51.9, 52.0, 52.1, 52.2, 52.3, 52.4, 52.5, 52.6, 52.7, 52.8, 52.9, 53.0, 53.1, 53.2, 53.3, 53.4, 53.5, 53.6, 53.7, 53.8, 53.9, 54.0, 54.1, 54.2, 54.3, 54.4, 54.5, 54.6, 54.7, 54.8, 54.9, 55.0, 55.1, 55.2, 55.3, 55.4, 55.5, 55.6, 55.7, 55.8, 55.9, 56.0, 56.1, 56.2, 56.3, 56.4, 56.5, 56.6, 56.7, 56.8, 56.9, 57.0, 57.1, 57.2, 57.3, 57.4, 57.5, 57.6, 57.7, 57.8, 57.9, 58.0, 58.1, 58.2, 58.3, 58.4, 58.5, 58.6, 58.7, 58.8, 58.9, 59.0, 59.1, 59.2, 59.3, 59.4, 59.5, 59.6, 59.7, 59.8, 59.9, 60.0, 60.1, 60.2, 60.3, 60.4, 60.5, 60.6, 60.7, 60.8, 60.9, 61.0, 61.1, 61.2, 61.3, 61.4, 61.5, 61.6, 61.7, 61.8, 61.9, 62.0, 62.1, 62.2, 62.3, 62.4, 62.5, 62.6, 62.7, 62.8, 62.9, 63.0, 63.1, 63.2, 63.3, 63.4, 63.5, 63.6, 63.7, 63.8, 63.9, 64.0, 64.1, 64.2, 64.3, 64.4, 64.5, 64.6, 64.7, 64.8, 64.9, 65.0, 65.1, 65.2, 65.3, 65.4, 65.5, 65.6, 65.7, 65.8, 65.9, 66.0, 66.1, 66.2, 66.3, 66.4, 66.5, 66.6, 66.7, 66.8, 66.9, 67.0, 67.1, 67.2, 67.3, 67.4, 67.5, 67.6, 67.7, 67.8, 67.9, 68.0, 68.1, 68.2, 68.3, 68.4, 68.5, 68.6, 68.7, 68.8, 68.9, 69.0, 69.1, 69.2, 69.3, 69.4, 69.5, 69.6, 69.7, 69.8, 69.9, 70.0, 70.1, 70.2, 70.3, 70.4, 70.5, 70.6, 70.7, 70.8, 70.9, 71.0, 71.1, 71.2, 71.3, 71.4, 71.5, 71.6, 71.7, 71.8, 71.9, 72.0, 72.1, 72.2, 72.3, 72.4, 72.5, 72.6, 72.7, 72.8, 72.9, 73.0, 73.1, 73.2, 73.3, 73.4, 73.5, 73.6, 73.7, 73.8, 73.9, 74.0, 74.1, 74.2, 74.3, 74.4, 74.5, 74.6, 74.7, 74.8, 74.9, 75.0, 75.1, 75.2, 75.3, 75.4, 75.5, 75.6, 75.7, 75.8, 75.9, 76.0, 76.1, 76.2, 76.3, 76.4, 76.5, 76.6, 76.7, 76.8, 76.9, 77.0, 77.1, 77.2, 77.3, 77.4, 77.5, 77.6, 77.7, 77.8, 77.9, 78.0, 78.1, 78.2, 78.3, 78.4, 78.5, 78.6, 78.7, 78.8, 78.9, 79.0, 79.1, 79.2, 79.3, 79.4, 79.5, 79.6, 79.7, 79.8, 79.9, 80.0, 80.1, 80.2, 80.3, 80.4, 80.5, 80.6, 80.7, 80.8, 80.9, 81.0, 81.1, 81.2, 81.3, 81.4, 81.5, 81.6, 81.7, 81.8, 81.9, 82.0, 82.1, 82.2, 82.3, 82.4, 82.5, 82.6, 82.7, 82.8, 82.9, 83.0, 83.1, 83.2, 83.3, 83.4, 83.5, 83.6, 83.7, 83.8, 83.9, 84.0, 84.1, 84.2, 84.3, 84.4, 84.5, 84.6, 84.7, 84.8, 84.9, 85.0, 85.1, 85.2, 85.3, 85.4, 85.5, 85.6, 85.7, 85.8, 85.9, 86.0, 86.1, 86.2, 86.3, 86.4, 86.5, 86.6, 86.7, 86.8, 86.9, 87.0, 87.1, 87.2, 87.3, 87.4, 87.5, 87.6, 87.7, 87.8, 87.9, 88.0, 88.1, 88.2, 88.3, 88.4, 88.5, 88.6, 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147.5, 147.6, 147.7, 147.8, 147.9, 148.0, 148.1, 148.2, 148.3, 148.4, 148.5, 148.6, 148.7, 148.8, 148.9, 149.0, 149.1, 149.2, 149.3, 149.4, 149.5, 149.6, 149.7, 149.8, 149.9, 150.0, 150.1, 150.2, 150.3, 150.4, 150.5, 150.6, 150.7, 150.8, 150.9, 151.0, 151.1, 151.2, 151.3, 151.4, 151.5, 151.6, 151.7, 151.8, 151.9, 152.0, 152.1, 152.2, 152.3, 152.4, 152.5, 152.6, 152.7, 152.8, 152.9, 153.0, 153.1, 153.2, 153.3, 153.4, 153.5, 153.6, 153.7, 153.8, 153.9, 154.0, 154.1, 154.2, 154.3, 154.4, 154.5, 154.6, 154.7, 154.8, 154.9, 155.0, 155.1, 155.2, 155.3, 155.4, 155.5, 155.6, 155.7, 155.8, 155.9, 156.0, 156.1, 156.2, 156.3, 156.4, 156.5, 156.6, 156.7, 156.8, 156.9, 157.0, 157.1, 157.2, 157.3, 157.4, 157.5, 157.6, 157.7, 157.8, 157.9, 158.0, 158.1, 158.2, 158.3, 158.4, 158.5, 158.6, 158.7, 158.8, 158.9, 159.0, 159.1, 159.2, 159.3, 159.4, 159.5, 159.6, 159.7, 159.8, 159.9, 160.0, 160.1, 160.2, 160.3, 160.4, 160.5, 160.6, 160.7, 160.8, 160.9, 161.0, 161.1, 161.2, 161.3, 161.4, 161.5, 161.6, 161.7, 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nearly always minus. On the few occasions when they were plus the average difference was 5.4 and the range from +10 to -6. On only one occasion was the weather clear, with a two-hour plus change in pressure, and then the minimum the next morning was 10° higher than the dew-point the previous evening. If we exclude this instance, the range will be from -6 to +3, and, as a rule, we should look for a minimum temperature about 3° or 4° lower than the dew-point the previous evening.

During the 10 mornings when the minimum temperature was 32° or lower, 6 were during clear weather, 1 with partly cloudy weather, and 3 with cloudy weather. On the clear nights the difference ranged from +18 to -1, on the partly cloudy night the difference was -5, and on the 3 cloudy nights the range was from -2 to -6. There were 8 mornings when the minimum temperature was lower than the previous dew-point, and on 5 of them freezing temperatures occurred, and on 3 mornings the temperature was above 32°, the warmest being 36°.

The highest current temperature followed by frost was 63°, the night being clear and very favorable for radiation. Two freezing temperatures occurred when the winds were light, four with winds from 5 to 10 miles an hour, and three with winds over 10 miles an hour, which shows there is apparently no connection between dew-points, freezing temperatures, and wind velocities, as the variations were as marked with light winds as with those that were stronger. Freezing temperatures occurred twice with north winds, four times with northwest winds, twice with southeast winds, and once with a south wind, and the variations were as marked with one direction as with another. If we consider the bearing the height of the barometer has on the agreement between the evening dew-point and the following minimum temperature, nothing conclusive is to be obtained. Freezing temperatures occurred once with a barometer as low as 29.80 inches, once 29.90 inches, three times 30 inches, twice 30.20 inches, once 30.30 inches, once 30.40 inches, and once 30.50 inches.

Regarding the position of the highs and lows, there were six cases with the high in the northwest and the low in the southeast, and the differences between the dew point and the following minimum temperature ranged from +10 to -4, with an average difference of +2.6. There was only one case for the other positions of the highs and lows, and no conclusions can be drawn from them. The principal freezing temperatures of the month occurred during the passage of a slow-moving high-pressure area from the north California coast to Cape Flattery and thence southeastward to the Great Salt Lake Basin. During the first two days the weather was cloudy and windy; then it became clear, and radiation was excellent.

From the foregoing analysis of the relationship between the evening dew point and the following minimum temperature we arrive at the following conclusions:

First. Dew-point observations taken from two to four hours later than the time of taking the regular evening observation agree more closely with the following minimum temperature than do those taken at the regular hour.

Second. The average difference and the range of the differences between the dew point and the following minimum temperature are greatest with clear or partly cloudy weather and least with cloudy weather.

Third. No inferences can be drawn from wind direction, wind velocity, steepness of barometric gradients, relative height of the barometer, and two-hour pressure changes as to the difference between the evening dew-point and the following minimum temperature.

Fourth. The position of the highs and lows gives important information at Medford regarding the differences between the evening dew-point and the following minimum temperature, and knowledge of this character is of some value at North Yakima, but of little use for the Boise district.

The investigation of the relationship of the evening dew point with the following minimum temperature, besides bringing out the preceding conclusions, also developed the fact that at North Yakima no freezing temperatures occurred when the wind backed a point or two after the 4.20 p. m. observation. Three freezing temperatures occurred when the wind veered a point, five when it remained steady, and one when it shifted from the south to the northwest. Also no damaging temperatures occurred at any place when the preceding maximum temperature was above 68°. At North Yakima the highest maximum temperature followed by a freezing temperature was 64°, and the highest current temperature was 61°; at Boise the highest maximum was 65° and the highest current was 63°; at Medford the highest maximum and the highest current were both 68°; and at Lewiston the highest maximum was 63° and the highest current 52°.

Mr. Thomas states in his report that "it was found that in fair weather, such as is favorable for frost, and also for uninterrupted radiation, the fall in temperature from the time of the maximum during the day to 10 p. m. was very nearly twice as much as it was from 10 p. m. to the time of the minimum the next morning."

To follow up this clue six nights at Medford, four at North Yakima, five at Lewiston, five at Clarkson, and four at Meridian have been selected as those best representing the conditions specified, viz, clear nights with good radiation weather, followed by minimum

temperatures of 32° or lower, and computations have been made to ascertain what the minimum temperature would be the next morning.

The average difference between the computed minimum temperature and the actual minimum temperature on these nights was 3.7°, and the absolute range was from 12° too high to 6° too low. There were 5 cases when the computed minimum temperature exactly agreed with the actual minimum temperature, and out of the total number of 24 cases there were 14, or a little over half, that did not vary more than 3°. This information, therefore, is of value to the local forecaster, but too much dependence should not be placed upon it, as the liability of error is great and the chances are that the estimated minimum temperature will be placed too high, which is a grievous fault.

At Lewiston and Clarkston there were three cases when the computed minimum temperature agreed with the actual minimum temperature, while in all the other cases the computed minimum temperature was too high. At Medford, on the other hand, there was one agreement and three cases when the computed minimum temperature was too low and only two cases when it was too high. It is possible that some of the dates selected did not entirely fulfill the conditions, but conditions are seldom perfect and frost must be predicted, when seemingly the winds are too strong and when there is more or less cloudiness to check radiation.

Another rule that can be followed by the local forecaster is to ascertain the median point between the maximum and minimum temperatures, find the average time it occurs, then take an observation of the temperature at that time, subtract the reading obtained from the maximum temperature, and the remainder will be the approximate fall that will occur to reach the minimum.

Computations after this plan have been made for the same dates as those used in testing the plan offered by Mr. Thomas. On account of the time error not having been noted on the thermograph sheets from some of the stations the exact median point can not be definitely located, but it is not far from 8.30 p. m. By considering 8.30 p. m. the halfway point between the maximum and the minimum temperature, we can arrive at a closer approximation to the minimum temperature than we can by waiting until 10 p. m. and considering that the temperature has fallen two-thirds of the range between the maximum and minimum temperatures. This method of arriving at an approximation offers the further advantage of giving the forecaster earlier information, which of itself is greatly to be desired.

The average differences under this plan are 2.9° as compared with 3.7° by the plan of Mr. Thomas. The variations are from +6 to -8, and there are 3 agreements and 16 cases where the computed mini-

imum temperature was too low and only 7 where it was too high. This is also an advantage, as it is better to make a mistake on the safe side than to predict that it will be warmer than what actually happens. At North Yakima and Meridian the agreements were remarkably close, and in no instance was the difference greater than 4°. At Lewiston, Medford, and Clarkston the agreements were not so close, but they were closer than were the computations based on the 10 p. m. formula.

Mr. Wells reports that a rather unsatisfactory investigation, made by Mr. C. A. Donnel, leads to the belief that "freely exposed thermometers read from 2° to 3° below the true air temperature." Professor Cox arrived at the same conclusion in his investigations in the cranberry marshes at Mather, Wis. He states:¹ The mean depression of the outside thermometers below those in the shelters at the six stations on the bog for the entire season of 1907 was 3°. Investigations made by Prof. Willis I. Milham at Williamstown, Mass., on 36 cold and cloudless nights showed the temperature averaged 3.9° lower in the open than in a shelter. It is probable that on frosty nights the difference between the true air temperature and the temperature indicated by thermometers hung on trees in orchards is not less than 3° and may average as much as 4°, with variations as great as 6° or 7°, depending upon the radiating qualities of the air, the density of vegetation, and the character of the soil.

The thermometers hung on trees, while not indicating the true air temperature, indicate, roughly, the temperature of the trees themselves, which is the temperature the orchardist is interested in, but it is not the temperature the forecaster can predict, because it varies so greatly in different orchards, and even in different parts of the same orchard.

The accepted standard for true air temperature is obtained by exposing a thermometer in a louvered shelter in an open place where the air can move freely through it. The shelter will keep the instruments dry and screen off the direct and reflected sunshine, which otherwise would affect the reading of the instruments. Instruments so exposed will read nearly alike if they are elevated a few feet above the ground and the territory covered is not too large and has the same physical characteristics. These are the temperatures that to a certain extent control the variations due to radiation from the vegetation and soil, and they are the temperatures that the forecaster endeavors to predict. The variations should be ascertained by the individual orchardist for himself. This can approximately be done by comparing the readings made in the orchard with those made in the louvered shelter.

¹ See p. 27, Weather Bureau Bulletin T.

Professor Cox¹ found that the temperature on cold nights varied a few rods apart as much as 6° or 8° in the cranberry marshes at Mather, Wis. It is probable we would not get quite so great differences in the orchards as he did in the cranberry marshes, but it would be considerable, and under similar conditions the same or very nearly the same every night. When an orchardist knows how the temperatures vary in his orchard and how these temperatures compare with those obtained in a louvered shelter in the neighborhood, it is an easy matter for him, with the help of the forecasts, to calculate just how cold it will be at his place whenever frost is predicted.

The responsibility for accurate forecasts should rest on the district forecaster for the prime "key" stations, upon the local forecaster for the secondary "key" stations and for the individual orchards as far as practicable, and upon the orchardist for his own immediate locality when the local forecaster can not handle that particular section for him.

The main reliance of the district forecaster is on his weather charts, which should be classified into types and studied from that point of view. Even with their help it is not always possible to prevent errors, as we all know how business men sometimes make mistakes in their accounts, which are based upon certainties, and we should not expect perfection in work that to some extent is based on uncertainties.

We have in this district damaging temperatures, effects of which can be classified under three heads: First, the common hoar frost, which occurs when the temperature sinks to the dew-point and the dew-point is below freezing; second, a dry freeze, when the temperature sinks below the freezing point and the dew-point is still lower than that mark; and, third, general freezes, when the air is thoroughly mixed and the whole mass is below freezing. The first two are usually the most damaging, but whether the dry freeze or the frost is the worst the writer does not know. Professor Brown, of the Corvallis Agricultural College, believes the most damage is done by the dry freeze, and he is probably correct in his surmise, as the thawing of a plant incased in ice would be slower than the thawing of one that was frozen without such a covering. It is a well-known fact that the slower the frozen plant thaws the less will be the damage done. In the case of the general freeze the weather is usually cloudy or partly cloudy and the winds are always somewhat brisk, if not actually strong. The thawing in such cases is always slow, and these freezes are the ones when the statement is so often made that "The damage was not so great as expected." The first two, occurring when there is but little or no wind, are due largely to radiation, and in the

¹ See Weather Bulletin T, p. 47.

last, provided it occurs when there is considerable wind, radiation plays but a small, if any, part in the process.

At North Yakima nearly all the damaging temperatures are with dry freezes, and hoar frost is seldom seen. At Boise and Lewiston frost sometimes forms, but sometimes the dew-point is too low and a dry freeze occurs. At Medford frost forms most frequently and dry freezes are rare. At all four places the general freeze occurs, and these are the most difficult to forecast on account of the dynamic heating that takes place in some of the valleys, which upsets the calculations. This is notably the case in the Boise district and to a less extent in the Yakima Valley. The general freeze occurs with a relatively low barometer and the other two classifications with a relatively high barometer and with clear or partly cloudy skies and quiet air.

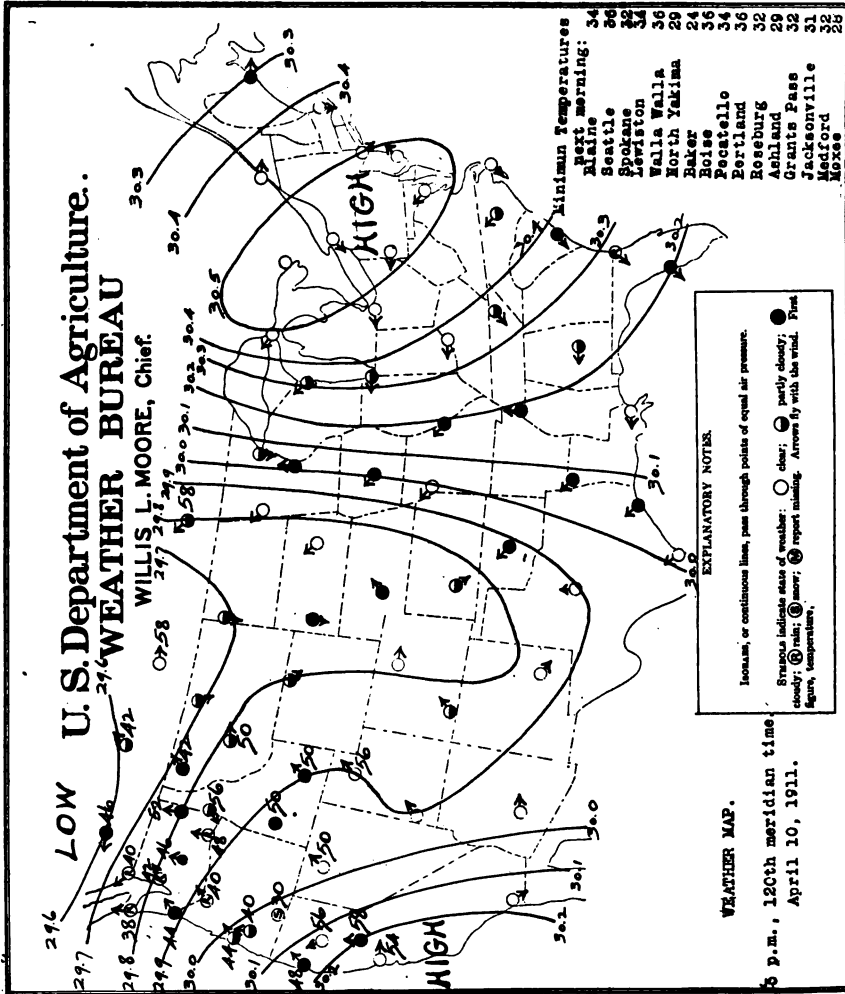
The five accompanying weather charts represent typical frost conditions, beginning with the general freeze where the whole mass of air reached a low temperature with general cloudiness and brisk southwesterly winds. As the high moved up the coast the clouds dissipated and the winds diminished in force until the air became comparatively still and radiation from the sun to the ground in the daytime and from the earth into space at night was uninterrupted. The coldest weather came during the first three days. After the high has reached its farthest point north and begins to move southeastward, the warming done in the daytime is so great that the loss at night is insufficient to cause very low temperatures.

It is not uncommon for high-pressure areas to make their appearance off the California coast, as in the case typified on Chart I, and then disappear without moving north, probably being influenced by low-pressure areas in the bight of the Pacific Ocean surrounded by the islands and coast line of southern Alaska. It is necessary for the forecaster to determine as early as possible whether or not the high-pressure area will have sufficient strength and character to assert its supremacy, and in doing this his largest asset is good judgment based upon past experiences.

Chart VI shows composite curves of the behavior of the thermometer between the time of the maximum temperature and the following minimum temperature. These traces cover only days with uninterrupted radiation, and they are interesting in showing that at North Yakima and Lewiston there are warm currents at night which interrupt the regularity of the curve, and they must be considered in making the forecasts of the degree of cold expected. Also at Medford the curve is sharpest and the Clarkston and Meridian curves are the most rounded at the time of lowest temperature. The rise from the lowest point is rapid and at all five stations the temperature is above

the freezing point by 7 a. m., except at Meridian, where the thawing weather does not set in until a half hour later.

From both the meteorological and pathological side of the problem it would seem that the best protective measures would be a combination heating device that would heat the orchards between 3 a. m. to sunrise and then throw out a dense smudge to screen the fruit from direct sunlight for three or four hours. Of course, during general freezes neither direct heating nor smudging will avail, but for dry freezes and frosts, especially the former, a smudge seems almost a necessity during the first few hours after sunrise on account of the rapid rise in temperature which the curves show at all of the places investigated.



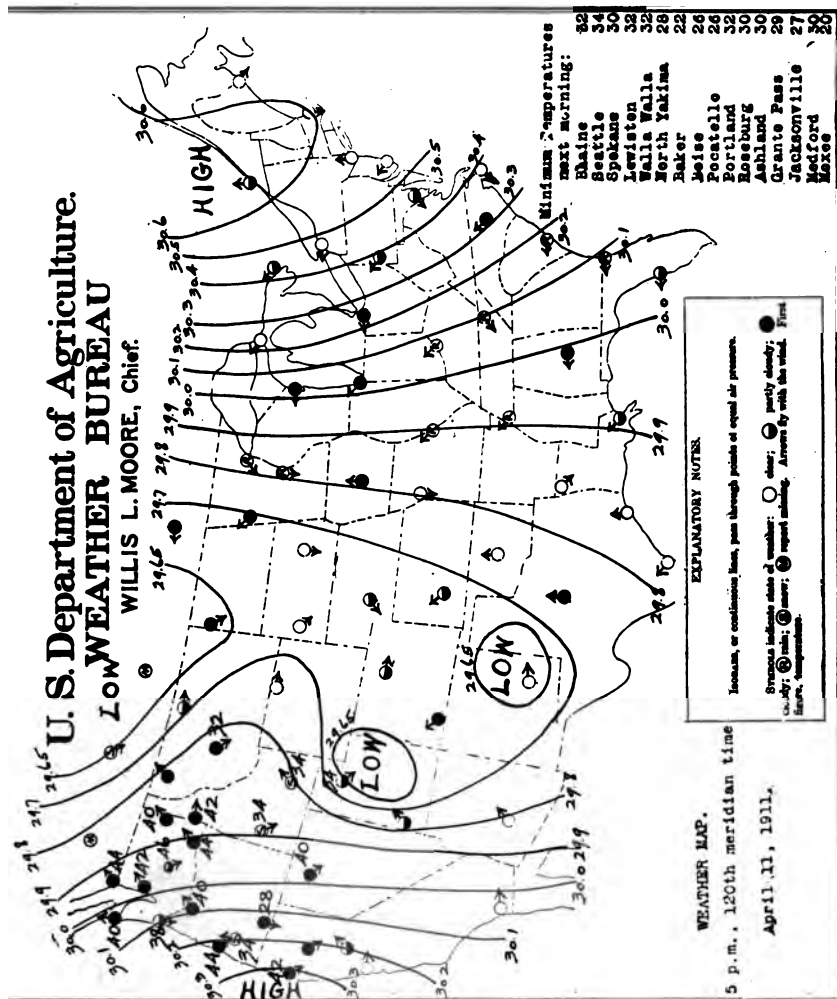


CHART II.

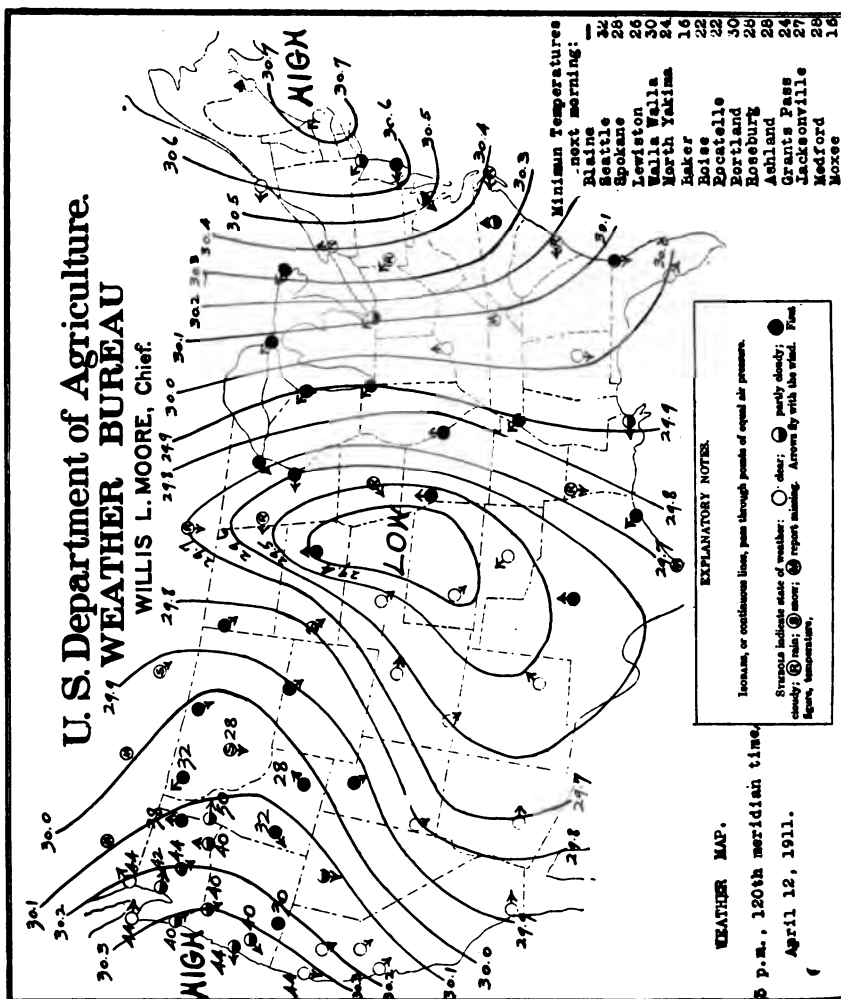


CHART III.

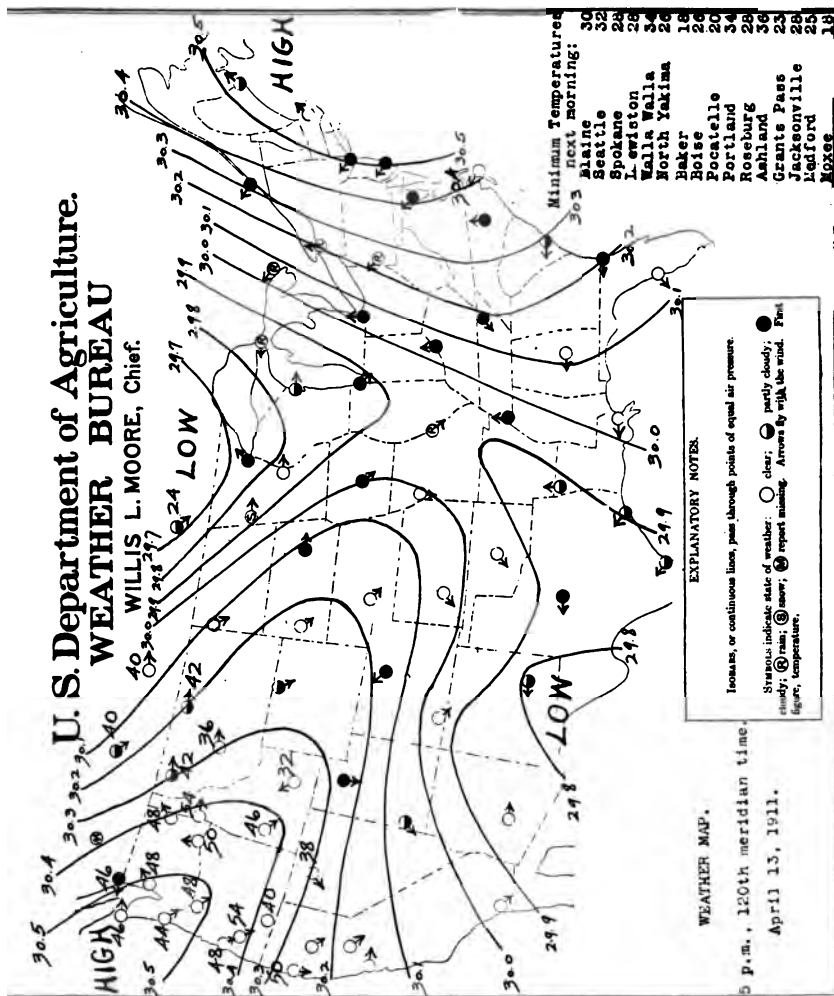


CHART IV.

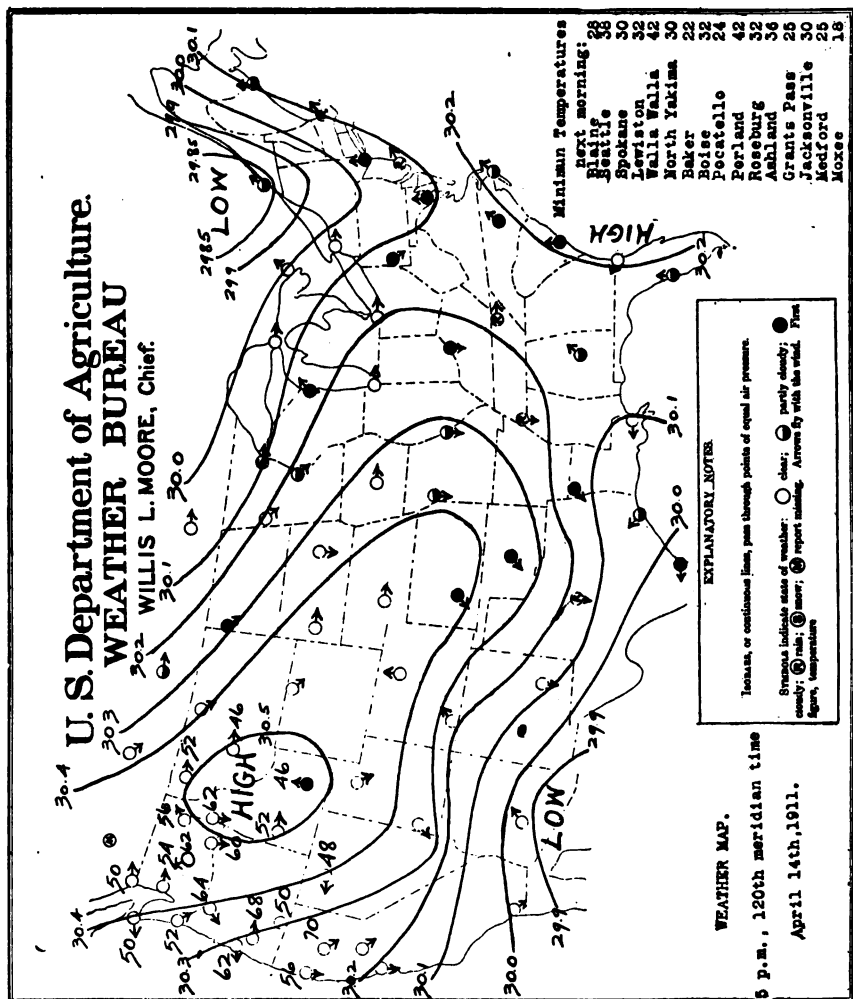


CHART V.

KILO-WATTS

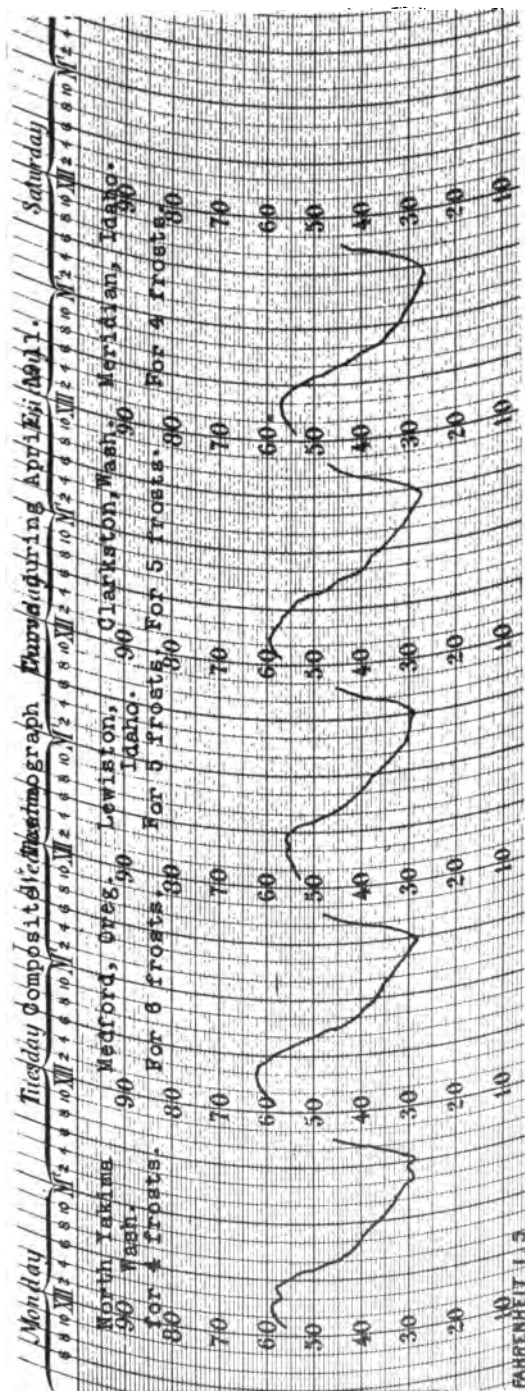


CHART VI.

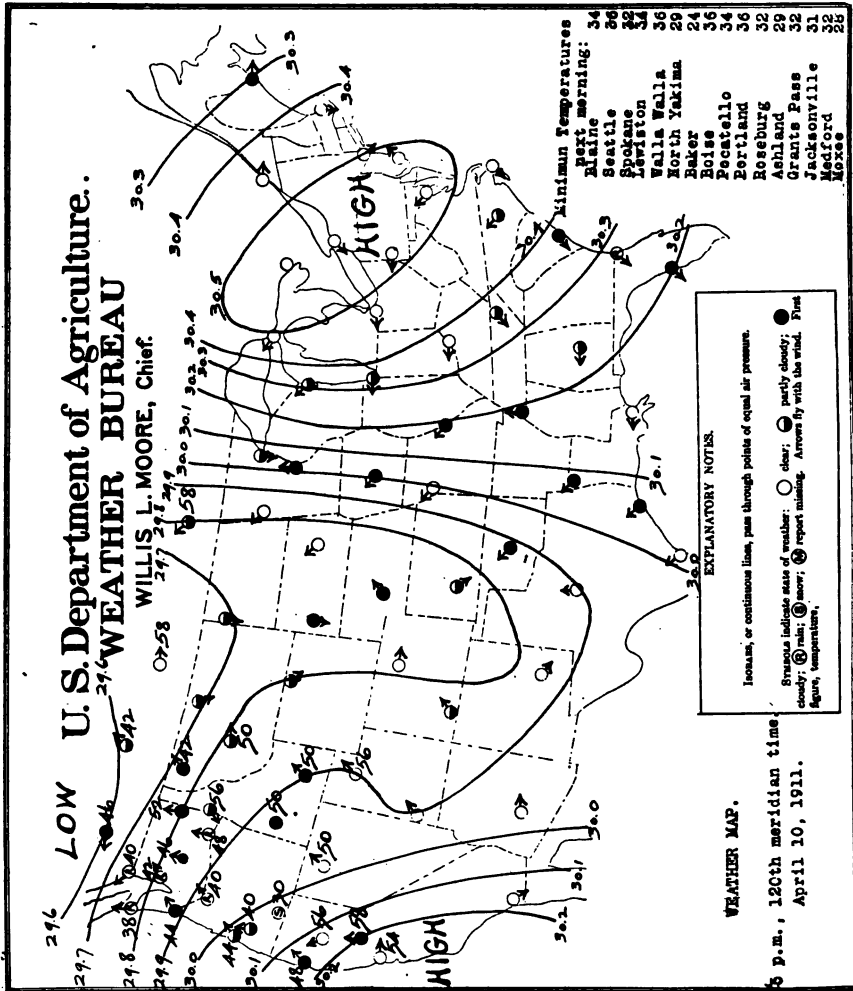


CHART I.

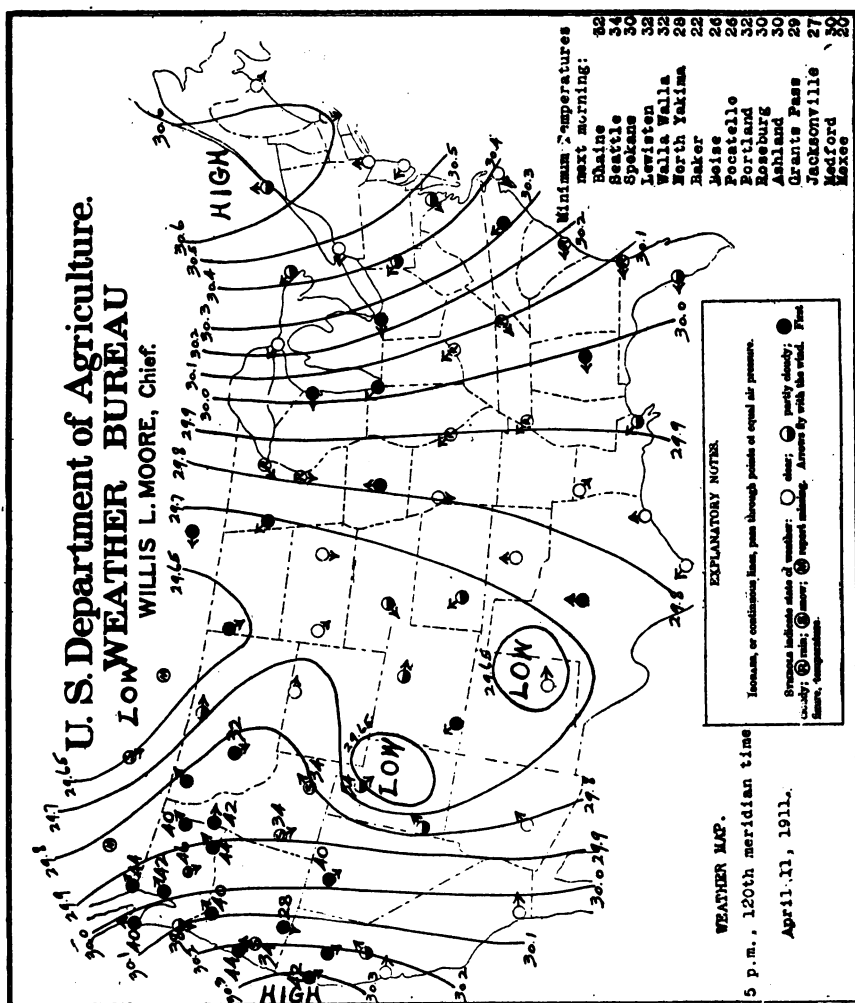


CHART II.

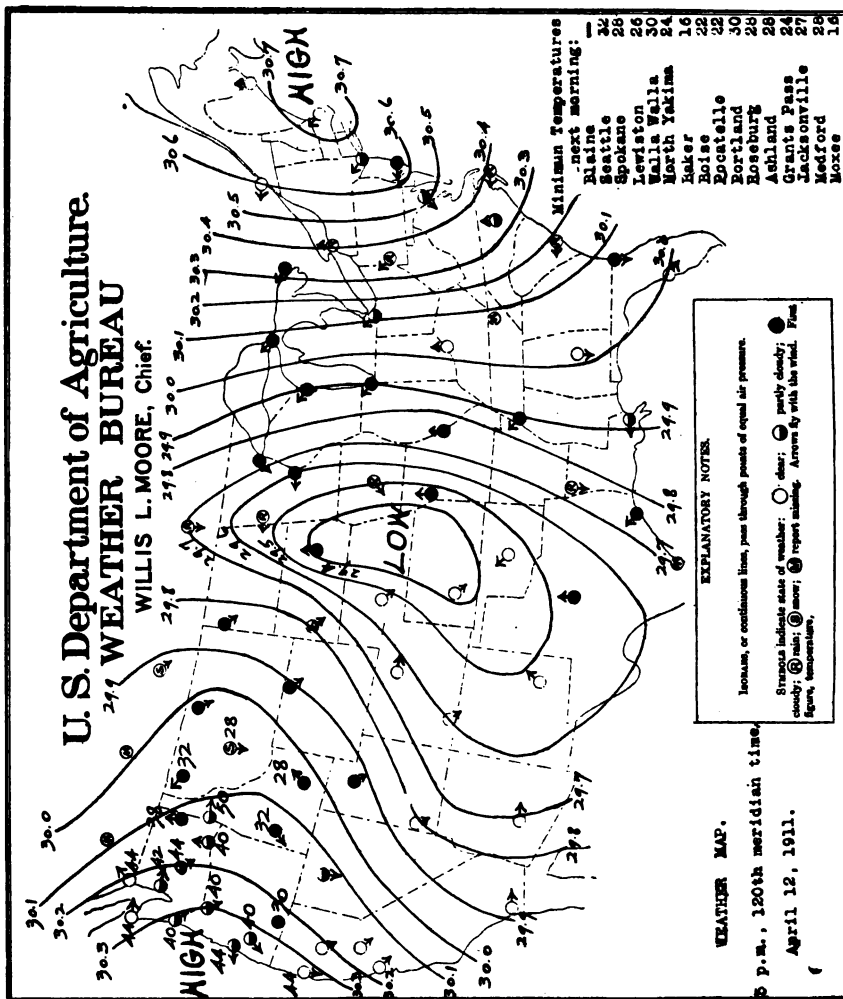


CHART III.

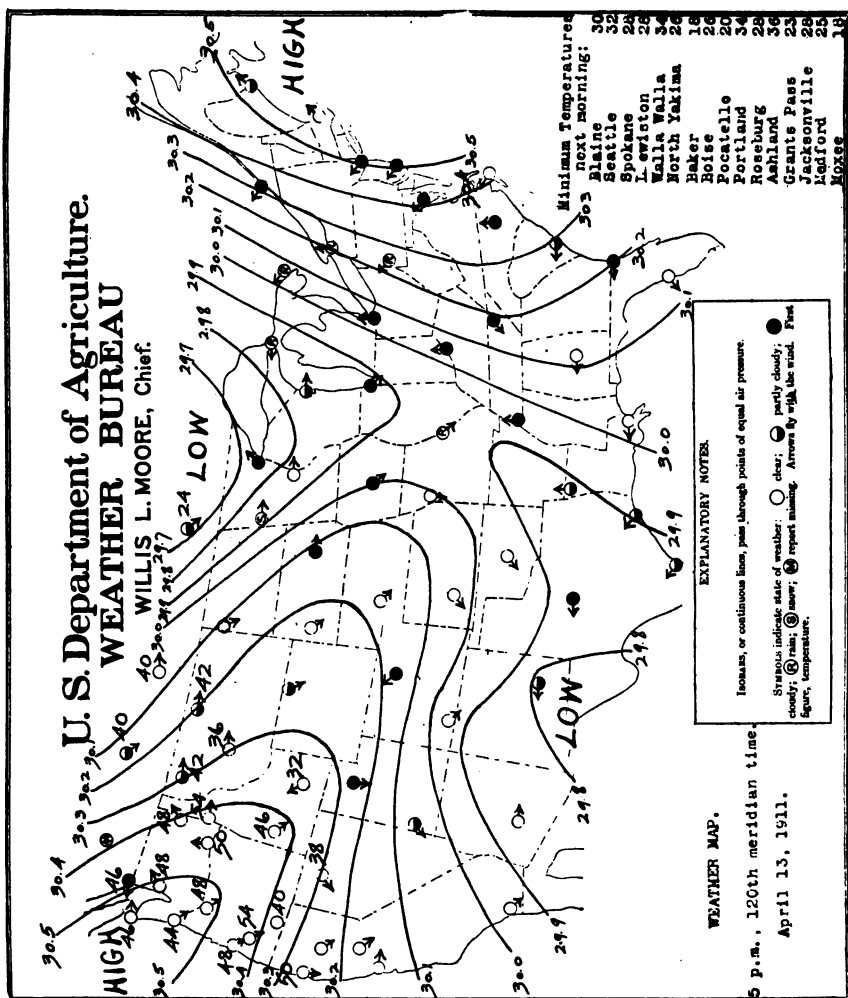


CHART IV.

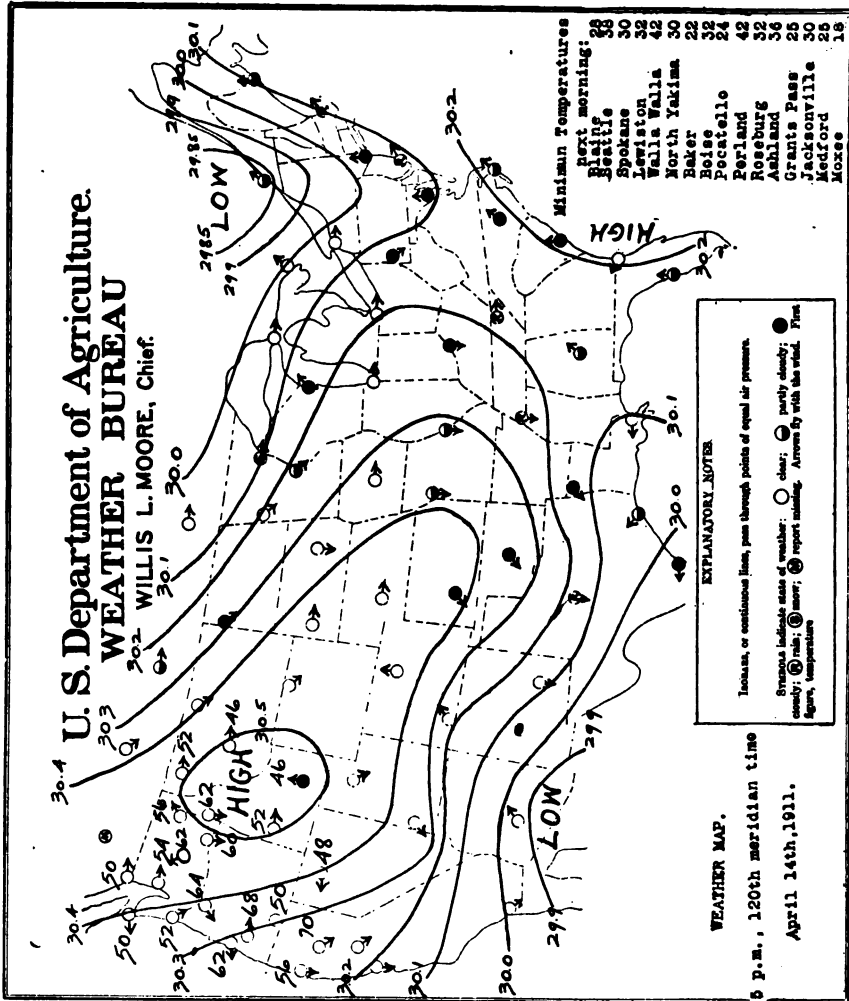


CHART V.

KILO-WATTS

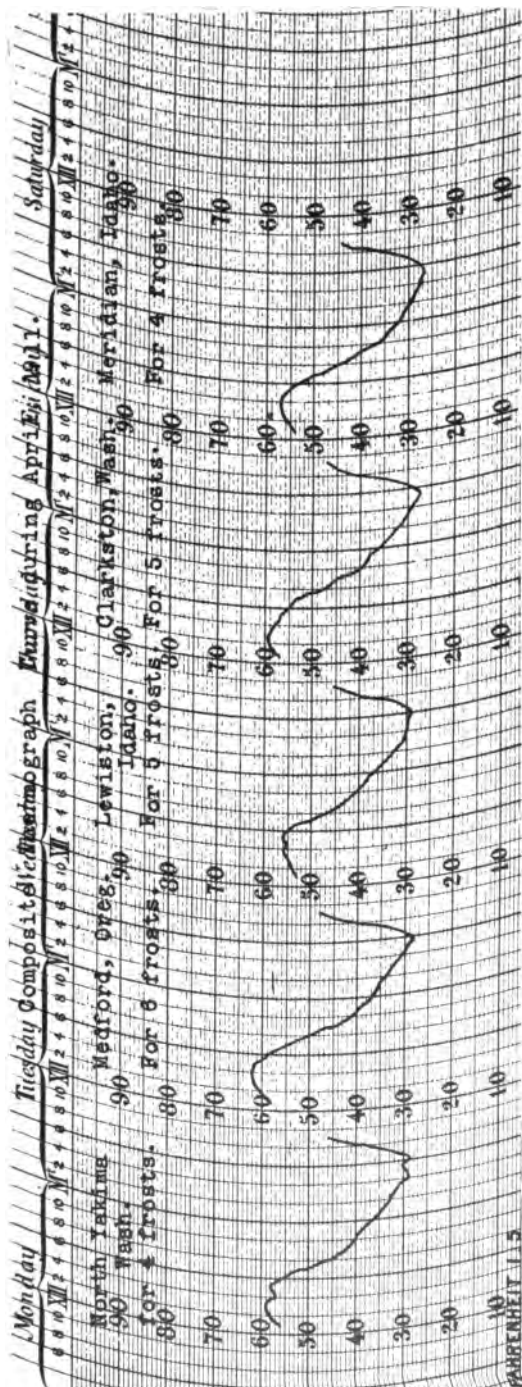


CHART VI.

11

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U. S. DEPARTMENT OF AGRICULTURE
WEATHER BUREAU.

FORECASTING THE WEATHER.

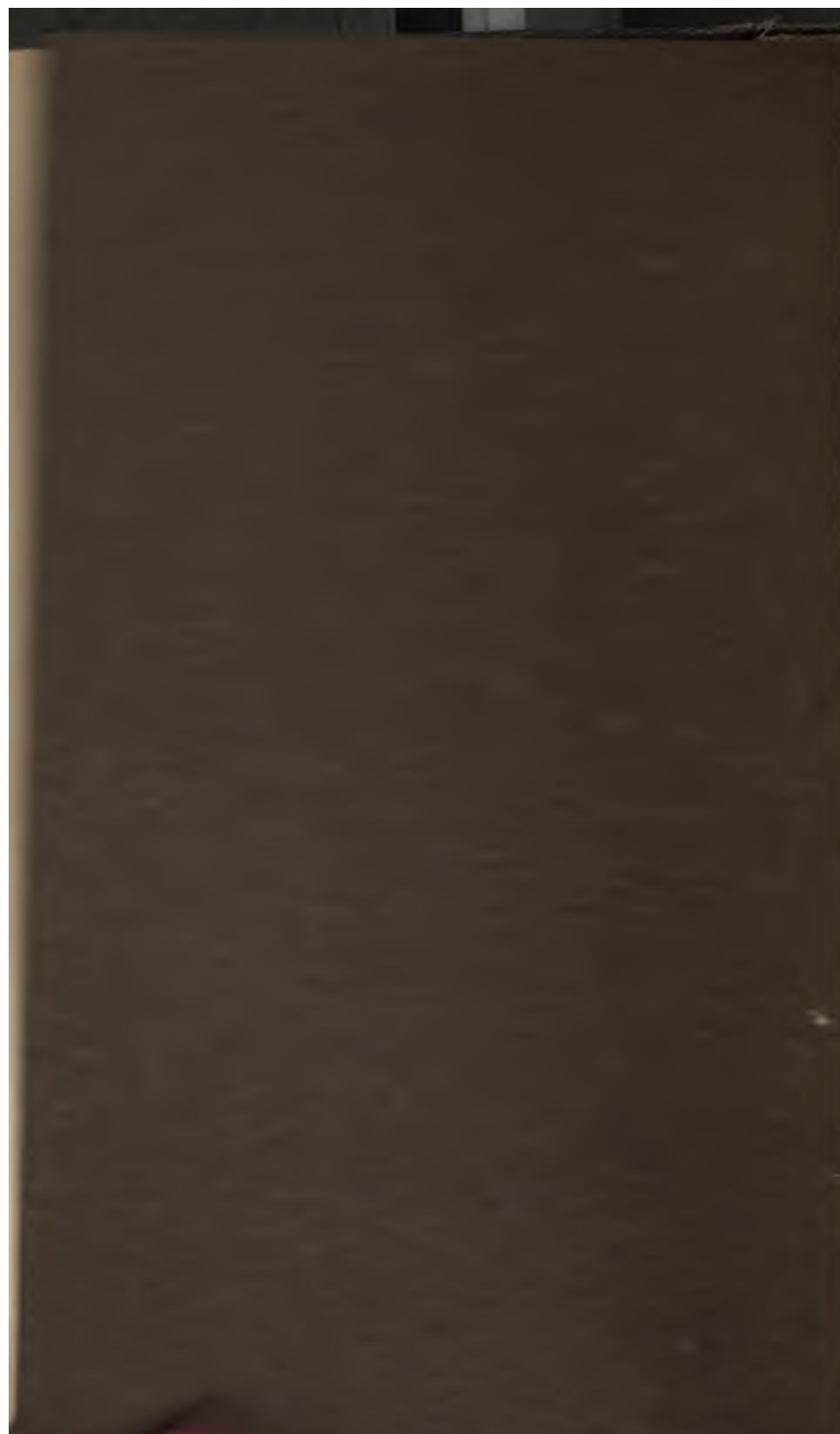
Prepared under the direction of WILLIAM L. MOORE, Chief of Weather Bureau.

BY

GEORGE C. BLISS,
SENIOR METEOR.



WASHINGTON:
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1918.



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U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.

FORECASTING THE WEATHER.

Prepared under the direction of WILLIS L. MOORE, Chief U. S. Weather Bureau,

BY

GEORGE S. BLISS,
SECTION DIRECTOR.



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PREFACE.

In this bulletin the precise style of the textbook is purposely avoided, the object being to present some of the generally accepted facts and theories of meteorology in an elementary form and in a comparatively inexpensive publication to permit of a wide circulation.

No pretense is made of advancing new theories or ideas, except the one of popular education along these lines.

The basic matter, as taught by Profs. Moore, Davis, Hann, Mill, and other recognized authorities, has been clothed in the author's own verbiage. Technical terms have been avoided so far as consistent, and the work has been made elementary to the extent of adopting the form of direct address, in some instances, as being most impressive and effective.

The subject matter was, in the main, first published as a series of newspaper articles, and has since been revised to its present form by direction of Chief of Weather Bureau to meet the numerous demands that followed its first publication.

In the revision the author was materially assisted by suggestions from Mr. Edward L. Wells, Mr. Roscoe Nunn, and Profs. Alexander McAdie and J. Warren Smith.

THE AUTHOR.

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FORECASTING THE WEATHER.

I. INTRODUCTORY.

If it were possible for a certain man to rise to a point every 12 hours where he could view the entire country from the Atlantic to the Pacific, from Canada to Mexico and the West India Islands, and if he could distinctly see the weather conditions over that entire territory and could watch the developments and movements of the storm areas, you would no doubt have a great deal of confidence in his ability to give out information regarding those conditions.

If on descending from one of his observations he should state that a storm area was moving in such a manner that its edge would pass near a given locality, you could readily understand that it would be a difficult matter to determine with certainty whether it would touch that particular locality or not.

Under such circumstances you would not call him a guesser if he should be in error 20 per cent of the time. You would say, "That man goes up where he can see all of the storms every 12 hours and can trace their movements continuously. He is able to outline ahead of each storm the greater portion of the territory that it will cover during the succeeding 24 to 36 hours. When the movements are somewhat irregular and the storms extend slightly beyond the territory outlined in some places and do not quite cover it in other places, it is a result that might reasonably be expected. On the average his information is accurate for more than four-fifths of the territory outlined, and such a high degree of success is surely not to be termed guess-work. If he can not tell with certainty regarding some localities then there is no use in others trying to do so, for he sees it all."

If any man could accomplish such a survey, what would his services be worth to the country? What would you think of the person who attempted to belittle his advice? Wouldn't it be plain to you that after obtaining a bird's-eye view of the whole country he would, at once, know more about the prevailing conditions than anyone else possibly could? Wouldn't you have a great deal of confidence in the opinions and advice that such a man offered, and wouldn't you defend him against all unjust criticism?

Difficult as such an achievement seems at first thought, the fact is that our Government maintains a weather service based on those same principles. The Weather Bureau of the United States Department

of Agriculture not only obtains, as it were, a bird's-eye view of atmospheric conditions over the entire country every 12 hours, but on special occasions it makes a survey of a severe storm area every 3 or 4 hours, following its movements and developments very closely until it spends its force or passes beyond the limits of observation.

When reading the forecasts and warnings issued by the Weather Bureau from time to time, you may not have realized that they were based upon such an elaborate system. Possibly you have been inclined to give equal confidence and credit to the opinions of certain individuals who talk mysteriously about the influence of the moon and the planets upon our weather, and who attempt to create the impression that the scientists of our Government Weather Bureau are groping in the darkness of ignorance.

It is the purpose of this pamphlet to explain how the seemingly impossible feat of obtaining an atmospheric survey of the entire country is accomplished, and to show that it is the only logical means of forecasting the weather. The following articles will also explain how the various phenomena that we experience in our daily weather changes are accomplished by physical forces in our atmosphere, and in a general way are well understood:

II. HOW IT IS DONE.

Of course it is impossible for anyone to attain an elevation from which to view the whole country at once, but equivalent results are obtained by another process.

The Weather Bureau maintains telegraphic observing stations in all parts of the country, there being something over 200 of them in all, and observers at these numerous viewpoints, all acting simultaneously, are able to accomplish just as satisfactory a survey as would be obtained by one person at a single viewpoint if such a thing were possible.

Every 12 hours, precisely at 7.45 a. m. and 7.45 p. m., seventy-fifth meridian time, the observers in all parts of the country begin the work of observing and recording the weather conditions, each in his respective territory. The sky is observed and the clouds are classified; the barometer is read and corrections are applied to obtain the corresponding reading for sea level, so that all barometers may show the value for the same plane; the direction and the velocity of the wind are noted; the rainfall or snowfall, if any, is measured; the current temperature and the extremes since the last previous observation are taken from the several thermometers; the moisture content of the atmosphere is calculated; and all other phenomena, such as thunderstorms, fog, smoke, halos, etc., are carefully noted. Each observer then condenses the information he has secured into

a telegraphic cipher message of 4 or 5 words, that when translated or expanded into descriptive language would comprise from 30 to 50 words. This work consumes about 15 minutes, and is completed at all stations by 8 o'clock.

The messages are rapidly transmitted to main line telegraphic circuits, and are collected at the central office in Washington, and are also interchanged between many of the larger cities where forecasters are stationed. At these various centers, the messages are translated as fast as they are received, and the conditions are inscribed in their respective places on an outline base map of the country by means of figures, letters, and symbols.

The locations of the observing stations are indicated by small circles. Where cloudiness prevails the whole area of the circle is blackened; for partly cloudy conditions one-half of the circle is blackened; while the whole is left clear to represent clear skies. If rain is falling at the time of observation an "R" is marked in the circle, or an "S" for snow, as the case may be. Arrows are inscribed to fly with the wind. The barometer reading, temperature, wind velocity in miles per hour, and the depth of precipitation (rain or snow), if any, are written by the side of each station in figures. The precipitation areas are outlined and shaded. Red lines are drawn through points of equal barometric readings, and indicate atmospheric disturbances, the significance of which will be explained in later chapters. Blue lines are drawn through points of equal temperature, and the completed chart is known as a weather map.

The work, from observations to map making, is all conducted under such specific rules and regulations that the finished map is as complete a bird's-eye view for the experienced forecaster as if he had beheld all the conditions with his own eyes.

In less than 2 hours from the time the observations are taken, the various forecasters are, figuratively speaking, standing on eminences overlooking the entire country, and are prepared to give out information regarding the weather conditions in any section as well as to forecast the probable developments for a day or two in advance. By means of the map, the forecaster is enabled to anticipate the conditions for another State or for a distant city with nearly as high a degree of accuracy as he can for his own locality.

It should be borne in mind that the information that the forecaster gives out regarding the conditions in any portion of the country is derived from the reports of actual observations and is distinctly accurate and reliable. The forecasts that he issues represent his conclusions regarding the probable movements and developments for the time specified, but human judgment must necessarily contain some element of error.

However, as in the supposed case of the man with the bird's-eye view, we must conclude that if the forecaster with so much information before him can not always anticipate the movements and developments accurately, it would be useless for one not so equipped to attempt to excel him.

III. A SHORT STUDY OF A WEATHER MAP.

If you have never studied the weather maps, but have merely glanced at them occasionally, thinking them to be only picture puzzles in which the lines are hopeless tangles and the figures and symbols represent nothing in particular, it will be interesting at this time to analyze a map and consider its prominent features.

At the end of this chapter is a map, selected because of its near approach to a theoretically ideal type that would well illustrate the general laws applicable to our atmospheric disturbances.

The isobars, or lines of equal barometer readings, form the most prominent feature of the map, as they locate the great centers of action. They are drawn for each tenth of an inch of variation. For example, the line marked "30.0" at each end passes through points where the barometer readings are just 30 inches. On one side of this line the readings are higher than 30 inches, and lines are drawn for each tenth of an inch increase until a center or crest is located and marked "High." On the other side lines are drawn for each tenth of an inch decrease until the center of the depression is located and marked "Low."

The real significance of barometer readings will be more fully explained in a chapter on "Atmospheric pressure," but for the present it will be sufficient to note that the isobars outline great atmospheric whirls or eddies.

Bearing in mind that the arrows are inscribed to fly with the wind, a careful inspection of the area having "Low" at the center will reveal the fact that the winds blow in toward the center, not directly, but spirally, just as water in passing down through a funnel flows around the center and approaches it gradually. You will further observe that the winds rotate about the center in a direction against the hands of a watch, face upward. Some places will be noted where the winds do not conform to the above rules, being temporarily deflected by local conditions. The more intense and energetic the disturbance becomes the more nearly will the wind movements conform to the general laws, as the forces in the great atmospheric eddy become strong enough to overcome local influences.

Now, if you will examine the area marked "High" at the center you will observe that the winds move in opposite directions from those in the "Low." In other words, they blow spirally outward

from the center. Also it will be noticed that the air currents flow in a compound curve from the center of the "High" toward the center of the "Low."

Since the surface winds, as indicated by the arrows, blow in toward the center of the "Low" from all directions, it becomes apparent at once that the air rises in the central area. Conversely, it is equally evident that the air is constantly settling down in the central area of the "High." The fact that the surface air currents flow from the center of the "High" toward the center of the "Low" suggests the idea that at some distance above the earth the rising air in the "Low" must flow toward the "High," and such indeed is the case.

It must not be imagined, however, that the interchange of air as noted above comprises the complete circulation of these areas, for if we were to map a larger territory we would discover adjacent disturbances with which the same relations are maintained.

The temperature conditions attending this atmospheric circulation are very interesting. Note that the freezing line (drawn through points having a temperature of 32° F.) begins in the extreme northeast, in central New Brunswick, and extends nearly due westward to a point north of the center of the "Low," and thence it sweeps southward nearly to the Texas coast, then northwestward into southern California, whence it bears northward nearly parallel to the Pacific coast line. A study of the wind directions with relation to this line will suggest some of the reasons for its trend.

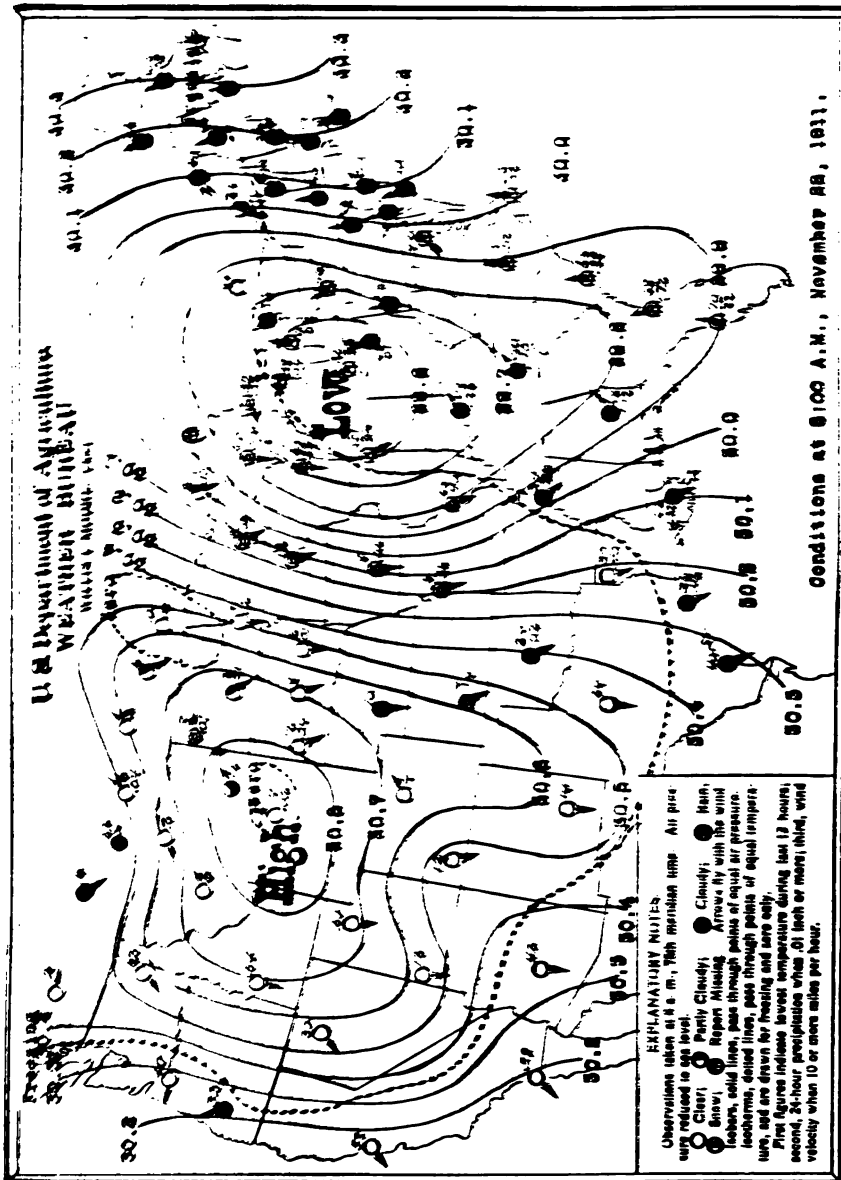
The weather conditions in these large atmospheric whirls are as remarkable as are the temperature conditions. Observe the prevailing cloudiness in the low-pressure area, bearing in mind that it is cloudy at the places marked with an "R" or an "S" the same as where the circles on the map are blackened. By way of contrast notice the clear skies over the greater portion of the high-pressure area.

Areas of high and low barometric pressure are constantly and successively drifting across the country from the west toward the east, and with the foregoing explanations the reader can readily understand the causes of our weather changes.

It becomes evident that while an area of low barometric pressure is drifting over a given locality the weather will ordinarily be cloudy, with a tendency to rain or snow, depending on the season of the year. The temperature will at first be comparatively high, followed by colder when the center of the area has passed and the wind shifts to a westerly or northwesterly direction. As the area of low pressure passes eastward and is succeeded by an area of high pressure, the temperature will continue to fall for a time and the skies will clear.

A rapid succession of high and low pressure areas implies frequent changes in weather and temperature conditions, while conversely

unsteadiness in the movements of these areas tends toward a pro-
longation of given types of weather.



IV. THE CONTRAST.

Thus far we have dwelt upon the similarity between the Weather Bureau map and a bird's-eye view of the country. Let us now contrast them and consider the numerous advantages that favor the map.

The person with a bird's-eye view could note the areas of cloudiness and sunshine, as we find them plotted on the weather map. He would necessarily be above the clouds and could not see where rain or snow was falling. Granting, however, that the types of clouds might enable him to closely approximate the precipitation areas, he would still be unable to determine the intensity or severity by measuring the amount of rain or snow fall. The Weather Bureau map gives all of this information accurately.

The bird's-eye view would enable the observer to determine the directions of the surface winds and to approximate their velocity in the clear areas by watching the drift of smoke, but in the cloudy areas he could only watch the cloud movements and estimate the surface winds from a general knowledge of atmospheric circulation. In high winds and gales he might catch occasional glimpses of heavy seas and of the destruction on land, but most of these effects would be obscured by intervening storm clouds. The observers of the Weather Bureau can see the cloud movements above and the effects of the storm underneath, and in addition they are enabled to measure the velocity of the surface winds.

The observer aloft could gain very little knowledge of the temperature. Under certain conditions he might see evidences of unusual extremes, but his knowledge would be crude and only approximate at the best. By means of the Weather Bureau map we may know exactly the temperature conditions in all parts of the country, and by comparison with previous maps we can see where they are rising and where they are falling. By taking a pencil and outlining the districts where the temperatures are rising and where they are falling, and then comparing maps, we can watch the movements of the warm and cold areas across the country just as clearly as we can that of the rain areas. By considering the amount of change that is taking place in any area, we can forecast for localities ahead of it as to whether the temperature change will be up or down and much or little.

A greater advantage than any or possibly all of those mentioned in favor of the weather map is the fact that it gives the barometer readings, thus accurately outlining the great atmospheric whirls or eddies and showing the slightest increase or decrease in energy. The man with the bird's-eye view could only approximate the territory covered by these disturbances, by means of noting the wind directions and the distribution of cloudiness, as explained in the preceding chapter. He could not detect moderate changes in energy or intensity.

Thus the observations, which are taken regularly every 12 hours by the Weather Bureau, are not only comprehensive bird's-eye views, but, more than that, they are complete and accurate surveys

of all the atmospheric conditions. When one comes to fully understand what the weather map represents, it takes on a new significance and an added importance. It is seen that the impossible bird's-eye view, as proposed in the first chapter, could not accomplish so much after all, and the private theories of the village weather prophet, which formerly seemed so plausible, become equally vaporous.

The distinctly practical and scientific methods of the Weather Bureau have no doubt appealed to the reader, but before making a closer analysis of the maps for the purpose of explaining more of the principles of forecasting, it will be advisable to study some of the more important characteristics of our atmosphere.

V. THE ATMOSPHERE.

The atmosphere is composed of a mixture of gases and surrounds or envelops the whole earth. It is sometimes likened to a great sea of gases, at the bottom of which we live without the power to rise to the surface. The principal constituents are oxygen and nitrogen, in about the proportion of 21 per cent of the former and 78 per cent of the latter, the remaining 1 per cent being made up of five other gases. Water vapor, which is really water in a gaseous form, is always present but is a variable quantity. It occupies space independent of the other gases, and may comprise from 1 to 5 per cent of the total weight of a given volume of air.

The tendency for these gases to escape into space is overcome by the earth's attraction, and they rest upon its surface with about the same weight as a layer of water 34 feet in depth. In other words they press downward, and obeying the law of gases they also press in every other direction at sea level at the rate of nearly 15 pounds per square inch of surface.

We can not see the gases, and since they permeate all our tissues we do not feel their pressure except when they are in motion as wind. It used to be supposed that the atmosphere had no weight, and hence the saying "light as air."

Since the density of air at sea level is only about one eight-hundredth part that of water, it follows that the atmosphere would be eight hundred times 34 feet, or about 5 miles in depth if it were of the same density at all altitudes, which it is not. Gases are easily compressed, and therefore the layers near sea level have the greatest density because they are compressed by the weight of all that lies above. With increase of distance above sea level this weight is decreased steadily by the amount of air that is left below, and thus the pressure and density gradually diminish to nothingness.

So much of the atmosphere is compressed into the lower layers that one-half of it lies below an elevation of $3\frac{1}{2}$ miles, although traces of its lighter gases have been revealed at an altitude of nearly 200

miles. Only one sixty-fourth of the atmosphere lies above an altitude of 21 miles, so we may realize that this gaseous envelope is relatively very thin as compared with the diameter of the earth.

The gases of the atmosphere are not in chemical combination, but are only mixed together, and according to Dalton's law each of them occupies space independent of the others. The lighter gases have the greater depth, and it is believed that hydrogen overcomes the earth's attraction and escapes into space. Nitrogen, which is the lightest atmospheric gas except hydrogen, is retained by the earth's attraction and forms what may be termed the outer limits of the atmosphere. Oxygen extends about four-fifths as high as the nitrogen, while water vapor and the heavier gases such as argon and carbon dioxide become very rare at the elevation of our highest mountain peaks.

The air holds in suspension many substances, such as bacteria and dust particles. We may sometimes think that it would be a great advantage to have all such foreign matter eliminated, but if so it is because we do not fully realize what the results would be.

Only a small portion of the bacteria are of the disease-breeding types, while many of the remainder are of real benefit to mankind. Bacteria are the chief factors in manufacturing all of the products of fermentation, and also they are the active agents that disintegrate the organic matters in the soil and prepare them for plant food.

The inanimate dust particles in the air are very important as they diffuse the sunlight and thus give a uniform illumination to the atmosphere. If the air were entirely freed from the dust and vapor particles, there would be a maximum of bright light and dense shadows.

VI. HEATING AND COOLING OF THE ATMOSPHERE.

In this short treatise of the processes of the heating and cooling of the atmosphere, it is deemed unnecessary to explain the causes of the change of the seasons, or why a change of conditions is experienced with a change in latitude on the earth's surface.

It has been found that oxygen and nitrogen absorb very little of the solar radiation during its passage downward through the atmosphere, and that most of this function is performed by the water vapor although the dust particles are also a factor. Since the water vapor practically disappears at an elevation of about 6 miles, it follows that the absorption of heat is very slight beyond that distance, and even at elevations of 4 or 5 miles it is small as compared with that at lower altitudes. From the fact that one-half of the atmospheric gases and more than four-fifths of the moisture lie below an elevation of $3\frac{1}{2}$ miles, it becomes evident that much more than one-half of the total absorption of solar heat takes place in these lower air strata.

Fully one-half of the solar radiation is ordinarily absorbed in its passage downward through the atmosphere, and of that which reaches the earth's surface a portion is absorbed while the remainder is reflected and is largely taken up during its outward passage through the moist lower air strata. The heat that is absorbed by the earth's surface is being constantly radiated and supplements that which is directly absorbed by the air. Also heat radiates more rapidly from a dry atmosphere than from a moist one, and thus as the moisture content decreases with increased elevation there is a corresponding increase in the rate of radiation.

In considering the conditions which affect the relative temperatures of the upper and lower air strata, we must admit another important factor which is of a dynamic character. When warm surface air is carried upward by rising currents the pressure upon it decreases steadily by the weight of air that is left below, and according to Boyle's law the gases must expand at such a rate that their density shall be constantly proportional to the pressure that they support. The work of expansion is performed against the force of gravity and consumes heat, thus lowering the temperature steadily at about the rate of 1° for every 270 feet of ascent. Conversely, if air from great altitudes is carried toward the earth the pressure upon it increases constantly and reduces its volume, but in this instance the work is performed on the air by the attraction of gravity, and thus raises its temperature.

By combining all these conditions it may be readily understood that the air strata near the surface are warmest, and that ordinarily the temperature decreases with increase of elevation. However, we sometimes have conditions known as inversions, in which the temperature increases with elevation for a few thousand feet. Also beyond the limits of the moisture content the temperature of the atmospheric gases is believed to be nearly constant at all elevations. The foregoing explanations account for the perpetual snow and ice on the tops of our loftiest mountains.

A water surface reflects a large portion of the heat that reaches it, while another large portion is used in the evaporation of moisture. The comparatively small amount that is absorbed warms the surface but little as it penetrates to a considerable depth. On the contrary, a land surface absorbs heat rapidly, reflects very little, and only a small portion is used in the evaporation of moisture. The portion that is absorbed does not penetrate deeply, and hence a given amount of heat will warm a land surface about four times as much as it will a water surface.

Inasmuch as the heat penetrates the water to a considerable depth, it is retained and radiates back slowly, while on the land it remains near the surface and radiates rapidly. A land surface heats and cools

faster than a water surface, and consequently the temperatures over the continents are subject to greater extremes and more rapid changes than those over the oceans. The difference between the conditions over the land and over the water are not so noticeable in coast districts because of the equalizing effects of the land and sea breezes, but there is a marked contrast between those over the interior of the continents and far out over the oceans.

From the foregoing it can readily be understood how very unequally the atmosphere is heated. The change of the seasons; the different latitudes with the consequent varying angles at which the sun's rays penetrate the atmosphere; the oceans and the continents; the mountains and the valleys; the sand deserts and the verdant fields; the clear skies and the varying cloud formations are all contributing factors to the unequal heating that keeps the atmosphere in continual motion.

VII. CIRCULATION OF THE ATMOSPHERE.

Cold air is heavier than warm air under corresponding conditions, because heat expands the atmospheric gases and makes them less dense. We can see this principle illustrated in the hot-air balloon which rises because the superheated air in the sack is lighter, volume for volume, than the colder surrounding air, and it is forced upward in the same manner that a cork when released under water is forced to the surface. In general we may assume that the greater the difference in the temperature of adjacent volumes of air, the more energetic will be the movement or action to restore equilibrium, which accounts for the violent local disturbances in the atmosphere.

Bearing in mind that superheated air rises, and at the same time considering the temperature conditions that obtain on various portions of the earth's surface, we may reason out some of the movements that actual observations have proven to exist. In the equatorial belt the superheated air is constantly rising and flowing out on either side toward the poles. The cooler surface air that flows steadily in from either side and displaces the warm rising air constitutes the trade winds, which blow from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere.

The air that rises in the equatorial belt and flows out on either side can not move directly toward the poles on account of the convergence of the meridians. In other words, air can not move from all sides toward a common center, and in much the same manner that water flows around the outer portion of a whirlpool and approaches the center gradually, so the air passes around the earth at intermediate altitudes and forms a cyclonic circulation in each hemisphere that is most marked in the temperate zones. The direction of the circulation is determined by a force arising from the rotation of the earth

flow to the right carries free moving particles to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

Both the easterly and westerly winds in the temperate regions, the monsoon winds and the surface convergences break the circulation of the cyclonic and anticyclonic eddies which are shown as highs and lows on the weather maps. The extent to which the surface convergences enter into the formation of highs and lows is problematical, but it is known that the continent of Asia, with its different types of mountain ranges from those of North America, is relatively free from such disturbances. The highs and lows are very shallow formations being only about 1 mile in depth and sometimes more than 1,000 miles in diameter and they are moved from west to east by the action of the upper easterly air currents. Local disturbances, such as thunderstorms, tornadoes, waterspouts, and squalls, occur within the lows while thunderstorms are not uncommon within the outer border of the highs.

The weather maps reveal the fact that the wind never blows in a straight line although usually it appears to do so. All of the atmospheric movements are in whirls or eddies large or small, the precise character of the whirl depending partly upon its size and partly upon surrounding conditions. All of the lesser disturbances, up to and including the high and low pressure areas shown on the weather maps, have a movement of translation in addition to the whirling or vortex circulation.

The most energetic air movements are tornadoes, which are local disturbances seldom more than 150 or 200 yards in diameter and which become so violent that the largest and strongest buildings are torn to pieces and strewn over their paths. In a tornado the depth is many times the diameter, so that the disturbance has a funnellike formation. In the larger disturbances, such as hurricanes and the large lows the area covered is relatively so great that they become very thin disks. The precise type of circulation must vary in these different formations, although it is cyclonic in each instance. A high may be likened to an inverted low, inasmuch as the circulation is the reverse of that in the low. The small dust whirls that we sometimes see in the street or over plowed fields illustrate the cyclonic principle of atmospheric circulation.

VIII. ATMOSPHERIC PRESSURE.

The pressure of the air is the prime element in the study of all of its movements, and careful measurements of the pressure over large areas enable us to outline the great atmospheric disturbances. The air pressure is merely the combined weight of all the atmospheric



gases, and as previously explained it is equal to a layer of water about 34 feet, or a layer of mercury about 30 inches, in depth at sea level.

The gases press equally in all directions at any given point, and consequently an open vessel, or any substance which the air can freely permeate, sustains no appreciable strain because it stands in the gases in the same manner as does a boat in the water when it is filled and sunk. If an empty boat should be loaded to its capacity and no water allowed to enter it, then the pressure of the water on its sides and bottom would be equal to the combined weight of the boat and the load, and if the framework should not be strong enough to resist such a pressure the boat would collapse. Similarly, if we should take an air-tight tank or barrel at sea level, seal it and exhaust all the air from within, the outer walls would then be subjected to a pressure of approximately 2,000 pounds per square foot. When we exhaust the air from within a rubber bulb, the bulb collapses because it is not rigid enough to withstand the outside pressure.

We do not feel the pressure of the atmosphere under ordinary conditions because air permeates all the tissues of the body. However, if it were possible to exhaust all the air from the body of an ordinary sized man, thus leaving him under the full influence of the outside pressure, he would be crushed by a weight of more than 14 tons.

By reducing, or entirely removing, the air pressure from one direction, it becomes perceptible and measurable from the other directions. A mercurial barometer is an instrument designed to utilize this principle, and in its simplest form it consists of a glass tube about 34 inches in length and sealed at one end. The tube is filled with mercury to exhaust all the air and is then inverted, with the open end resting in a cup of mercury. When the mercury starts to flow out of the tube it leaves a vacuum above it, thus removing all the air pressure from above on the surface of the mercury that is in the tube. Enough mercury will remain in the tube to balance the atmospheric pressure on the exposed surface of the mercury in the cup. To be more exact we should say that the weight of the mercury in the tube balances the pressure on such a portion of the surface of the mercury in the cup as would equal in area a cross section of the glass tube. Thus an increase or decrease in the area of the exposed surface makes no difference in the results.

A barometer may be constructed by using water or other liquids instead of mercury, but since the atmospheric pressure is equal to a layer of water about 34 feet in depth it becomes evident that the glass tube would need to rise more than 34 feet above the surface of the water in the cup. The barometer was invented in 1643 by Torricelli, a pupil of Galileo.

A standard barometer consists of the above-described simple instrument incased in metal for better protection. A scale and vernier are attached near the upper end of the tube to facilitate accurate readings of the height of the mercurial column. An ivory point establishes zero of the column, or the point to which the surface of the mercury in the cup must be adjusted before reading. With these accessories the instrument becomes a fine balance, more sensitive and accurate than an apothecary's scales.

Aneroid barometers are designed for portability and are much less sensitive and accurate than the mercurial instruments. Instead of being true balances, they utilize the principle of the spring scale. The legends "Fair," "Change," "Rain," and "Stormy," often found on the dials, have no significance, and are commonly placed only on popular-priced instruments of medium or inferior quality.

Barometers, of either type, actually weigh the pressure of the atmosphere, and if their indications were expressed in pounds, ounces, drams, and grains instead of giving the height of the mercurial column, or its equivalent pressure, in inches and fractions of inches, the instruments would seem less mysterious to the average mind.

The passage of the great areas of high and low pressure across the country causes the mercury in the barometers to fluctuate slowly but continuously. The change is not so much as is commonly supposed but is very significant. In 40 years of Government weather records in Philadelphia, the highest barometer recorded is 30.96 inches and the lowest is 28.69, thus making an extreme range of 2.27 inches. This indicates a difference in pressure of about 160 pounds per square foot of surface, and is the same change as would be experienced in rising from sea level to an altitude of 2,150 feet. It is unusual for a barometer to change as much as an inch in 24 hours, and such a change indicates an energetic disturbance moving at a rapid rate.

IX. RELATION OF AIR PRESSURE TO WIND MOVEMENT.

Barometric gradient is a term used to express increase or decrease of pressure along a horizontal surface between two points, and upon its steepness depends the energy of a storm and the rate of the attendant wind velocities. Thus if a crest of high pressure was over Bismarck, N. Dak., with a barometer reading of 31 inches, and at the same time a center of low pressure was over Philadelphia, with a barometer reading of 29 inches, the barometric gradient between the two places would be said to be very steep. On mapping such conditions the isobars would be close together, the pressure formations would be intense and energetic, and high winds would prevail between the two centers.

As explained in a previous chapter, the air currents flow from regions of high pressure over certain curved lines toward regions of low pressure, and the barometric gradient determines the velocity of the wind. As the air currents approach a center of low pressure their velocity normally increases until they reach a point where the horizontal component is partly overcome by being deflected upward near the center. To understand this, you may observe, when pouring water through a funnel, that it moves faster near the center than it does toward the outer edge. This phenomenon is in accordance with a well known mathematical law.

In West Indian hurricanes the barometric gradients are usually very steep, which accounts for the destructive gales of wind that are developed. The relation of the velocity of the wind to the barometric gradient is sometimes likened to water flowing down an incline, but the illustration is not in all respects a good one.

X. WATER VAPOR.

Heat breaks water up into its molecules, and imparts to it many of the properties of a gas. In fact, water vapor is commonly defined as being water in a gaseous state. It is different from most gases in that it can change from a gaseous to a solid form, as from vapor to frost, without passing through the liquid state, and conversely, ice and snow may pass directly into water vapor without becoming liquid.

The heat energy that is required in the process of evaporation is rendered latent, or imperceptible by any means, until the vapor is condensed back into visible water particles, when it is freed again as sensible heat. It is therefore easily understood that evaporation from a moist surface has a cooling effect, and the more rapid the evaporation the faster will the heat energy become latent and the greater will be the cooling effect.

We commonly speak of moist and dry air with the implied meaning that the gases of the atmosphere soak up the vapor much as a sponge would take up water, and the matter is probably understood in that light by many; but the fact is that the vapor occupies space practically independent of the other gases. At any given temperature, the same amount of vapor can be diffused through a vacuum as through an equal volume of air at sea-level pressure.

The amount of vapor that can be diffused through a given space is governed almost entirely by the temperature, and the amount of moisture can be practically doubled with each increase of 20° within the ordinary ranges experienced in the free air. Thus by raising the temperature from zero to 80° , the capacity of a given space for moisture is increased almost sixteenfold.

Water vapor is invisible until the space which it occupies is supplied to the limit of its capacity at that temperature, after which any additional moisture becomes visible as steam, fog, or cloud, which are all really identical in formation. A reduction of temperature under such conditions will also cause condensation by reducing the capacity of the space for holding vapor, which is virtually the same as adding vapor beyond the capacity.

If we could look into the boiler of an engine nothing would be visible above the surface of the water which it contained, although the pressure of the vapor might be 150 pounds or more to the square inch. The temperature in the boiler would be very high, and the instant that the vapor escaped from it into the free air it would be condensed by its expansion and sudden cooling and would become visible. When vapor is beginning to condense into visible fog, a rise in temperature will cause it to again become invisible.

Night fog is caused by the radiation of heat from the surface of the ground and from the adjacent air strata until the temperature falls to a point where a portion of the atmospheric vapor condenses. The temperature at which such condensation begins is known as the dew point, and at that time we say that the atmosphere is saturated. Saturation occurs in a dense fog, which is like a cloud at the surface of the earth instead of at a higher elevation as usually seen.

At times there may be present in the atmosphere only one-half or three-fourths of the amount of moisture needed for saturation, and when this amount is considered with relation to the amount necessary for saturation it is termed relative humidity. Thus we may say that the relative humidity is 40 per cent, meaning that two-fifths, or 40 per cent, as much moisture is present as would be needed for saturation at that temperature.

The rate of evaporation from any water or moist surface is mainly controlled by two factors namely, the air movement and the relative humidity. Water vapor exerts a certain pressure that is not produced by the other gases on a water surface, and this pressure has a controlling effect on the rate of evaporation. When saturation occurs the vapor pressure is such that evaporation becomes almost nothing, and at such a time if the air were to become quiescent it is probable that evaporation would cease entirely. Thus during a period of high temperature and light winds the conditions become oppressive if there is much moisture present, or, in other words, if the relative humidity is high, because at such times the perspiration is evaporated from our bodies slowly and we do not experience the cooling effects that accompanied a drier atmosphere or stronger winds, with the rate of evaporation much greater.

The condensation of water vapor into visible particles seems to require some solid substance upon which to collect. Thus you have

noticed the moisture condense on the outside of a pitcher of ice water. The cold pitcher reduces the temperature of the adjacent air below the dew point and the surface of the pitcher forms the solid substance upon which the moisture can collect.

When condensation takes place in the free air the dust particles act as the substance upon which the moisture can collect, and each minute water globule contains a dust mote. This is true whether condensation takes place as fog near the earth's surface or as clouds at high altitudes. Atmosphere entirely free from dust has been artificially cooled far below the dew point without condensation, but upon admitting a little puff of dust-laden air the moisture condensed into fog immediately. The necessary dust particles are carried up into the higher altitudes by the same air currents that carry up the water vapor, and air currents carry dust from the continents across the oceans, thus facilitating the condensation of water vapor in all parts of the globe.

At night in summer time the radiation cools the surfaces of vegetation below the dew point of the adjacent air, and the moisture collects on the leaves in precisely the same manner as it does on a pitcher of ice water. Very little, if any, moisture is seen on the pavements or other solid substances which absorb so much heat during the day that they do not cool below the dew point at night.

When condensation takes place on any surface the temperature of which is below the freezing point, it forms frost instead of dew. Remember that dew does not "fall" according to the common expression, but the moisture collects from the air that comes directly into contact with the cooled surfaces.

XI. PRECIPITATION.

Rain, snow, hail, and sleet are all comprehended in the general term "precipitation," and their differences in character are due to the conditions under which they are formed. Thus, while dew, frost, and low fog are caused principally by the cooling from radiation, the formation of rain, snow, hail, and sleet is due to the process of cooling that ordinarily attends the expansion of rising air currents.

If the dust particles in the rising air are plentiful and the ascent is not too rapid, the moisture will condense on the dust in extremely small globules, which, being very light, will be supported by the rising air and will float along as clouds instead of falling to the earth as a mist. If the ascent should be rapid and the dust particles few, a larger amount of water will collect around each dust mote and the globules will become heavy enough to fall through the rising air currents to the earth. Thus raindrops form mostly in the upper portions of the clouds, where the cooling is greatest and where the dust particles are fewest, and then in falling through the clouds they collect more moisture and increase in size.

If the vertical air currents are intermittent and quite strong, as in a thunderstorm, the raindrops are sometimes carried back and forth through the clouds, accumulating the smaller water globules until they become very large. The condition of the atmosphere between the clouds and the earth with regard to moisture is also a considerable factor in determining the size of the raindrops. When this atmosphere is almost saturated the raindrops may increase in size while passing through it, while conversely a warm dry atmosphere may evaporate the rain before it reaches the earth. It is not an uncommon occurrence on a warm summer afternoon to note rain falling from a cloud and gradually evaporating until it can no longer be followed by the eye.

The difference between rain and snow is similar to that between dew and frost. When condensation in the free air occurs with the temperature below freezing, the vapor passes directly into the form of minute ice crystals without first forming water globules. Hundreds of these ice crystals unite to form a snowflake. When snowflakes are examined under a microscope they are found to form regular six-sided figures in an almost endless variety of geometrical designs. Under ordinary conditions it takes from 8 to 12 inches of snow to equal in moisture 1 inch of water.

The formation of hail has never come under direct observation as has that of dew, fog, frost, rain, and snow, and consequently our knowledge of the process is largely theoretical. The conclusions in this respect are based upon two phenomena. First, true hail occurs only in warm weather and is usually an accompaniment of thunderstorms where strong vertical air currents are present. Second, on cutting a hailstone through the center it is found to be made up of concentric layers of snow and ice.

It is therefore reasoned that the hailstone formation is begun by a raindrop being carried to such an altitude that the expanding air about it is cooled below the freezing point, and therefore the drop is frozen, then falling back into the warmer stratum of cloud and rain, where its cold surface immediately collects a coating of water, only to be carried by another gust of rising air back into the higher altitudes to be frozen. This process is continued by the intermittent gusts of rising air until the hailstone becomes so large that it can no longer be supported aloft, when it falls to the earth. Sometimes several hailstones touch and freeze together, falling to the earth as a large irregular chunk of ice.

During the winter season rain sometimes forms in a stratum of air where the temperature is slightly above freezing and afterwards falls through colder air strata and reaches the earth in the form of frozen rain drops or ice pellets. This form of precipitation is not hail but sleet. Sometimes the raindrops and ice pellets are mixed, with the *temperature practically at the freezing point*, and if the surface air

temperature is below freezing a coating of ice is formed on every exposed surface.

The processes of condensation and precipitation are on such a stupendous scale in nature, even during the progress of a light shower, that all the artificial forces controllable by man are puny by comparison. The stories sometimes circulated regarding the accomplishments of so-called rainmakers fail to take into account the general atmospheric conditions prevailing at the time. When showers follow the rainmaker's operations and he therefore claims success the weather map almost invariably shows rain over too large an area to have been the result of local agitation, no matter how seemingly violent that agitation may have been. A clear sky, locally, at the beginning of the operation does not argue that the showers which may follow are the result of the rainmaker's efforts.

XII. WEATHER FORECASTING.

You can now begin to apply to the weather map the principles learned in a cursory study of the elements, and by so doing you can begin to anticipate storm movements and developments. Many changes occur in the atmospheric disturbances during their progress across the country, owing to the continual shifting of their relative location with regard to mountains, lakes, the seashore, or to extensive dry plains. It must be remembered that the barometric pressure areas are only formations through which the atmosphere circulates and that they do not carry a given quantity of air with them across the continent.

Weather forecasting consists in watching the storm movements and developments by means of the weather maps, in anticipating the changes that will take place in them, in estimating the expanse of territory that will be covered and the time that given points will be reached, and thereby determining the weather conditions that may reasonably be expected in each locality during the ensuing 36 to 48 hours. A chart, showing average storm tracks and average daily movements in the United States, will be found at the end of this chapter.

About 60 per cent of the areas of low barometer in the United States are first seen over the extreme northwestern portion of the country, and thence they move eastward along the northern border, across the Great Lakes, and finally pass off the north Atlantic coast. From your knowledge of the elements you can now reason out the changes that may be expected to occur within these disturbances during their progress over this northern route.

When a low-pressure area is central over Idaho, for example, you can readily understand that the precipitation within it will ordinarily be light, inasmuch as the air that circulates through it *flows in from comparatively dry regions*. The air currents from

the Pacific rise rapidly as they flow inland and, cooling by expansion, they are deprived of a large portion of their moisture on the western side of the Cascade range of mountains.

When the center of the disturbance has moved eastward across the Rocky Mountains the rainfall begins to increase in the eastern side of the area, occasioned by the greater quantity of moisture in the atmosphere that flows in from the central valleys and from the western portion of the Lake region. From thence eastward the storm usually increases in energy as it reaches into lower altitudes and moister regions, but ordinarily these disturbances do not cause heavy or excessive precipitation.

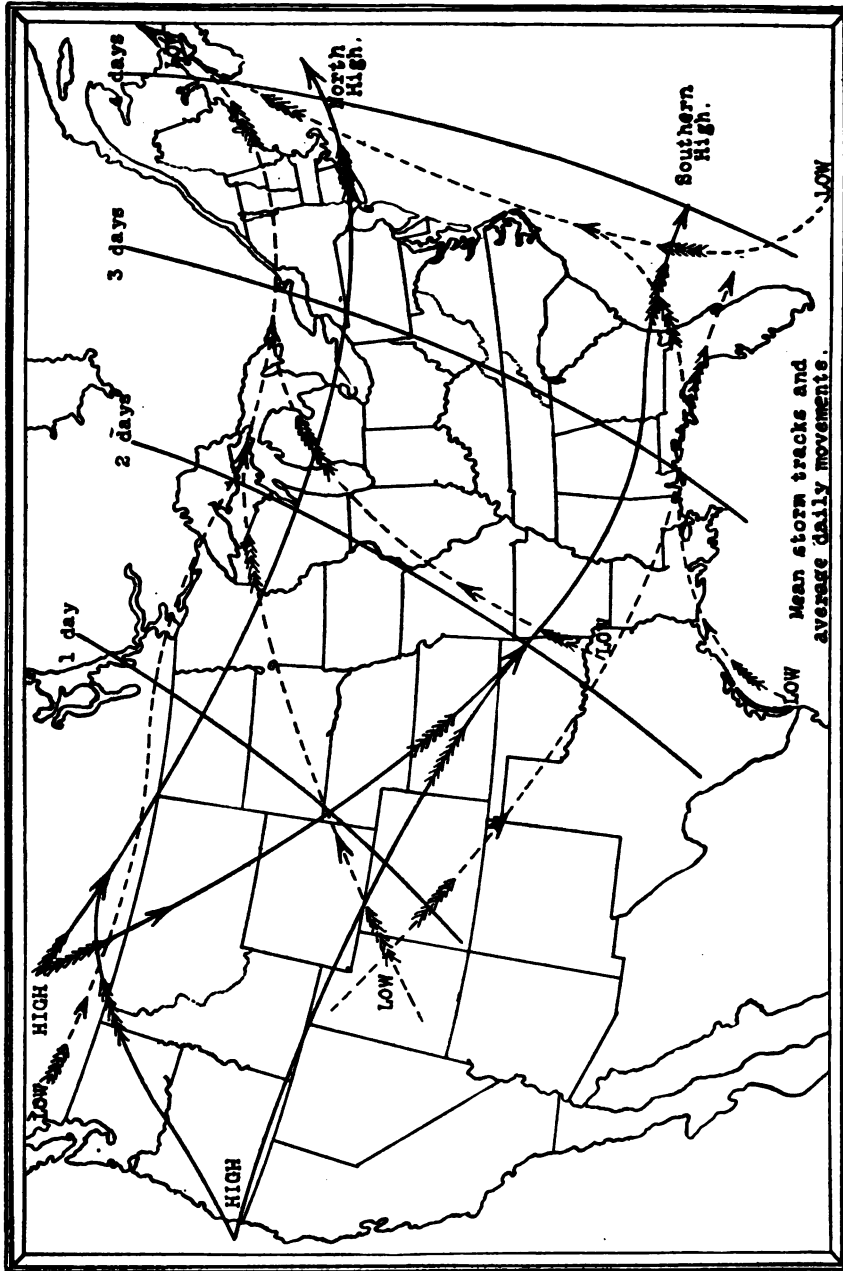
The low-pressure areas that are first seen over the southern plains, and those that move into the Southern States from the Gulf of Mexico, generally drift northeastward and pass off the north Atlantic coast. They are usually more intense and energetic than the disturbances that cross the country along the northern border because they move through moister and warmer regions.

Now conceive a well-developed storm to be central over northern Texas and drifting toward the New England States. During the entire time that it is crossing the great central valleys it is drawing warm air currents from the Gulf of Mexico heavily laden with moisture. The rainfall attending such storms is generally heavy, and their passage sometimes breaks up severe droughts in the great corn and wheat belts. As these storms move farther northeastward they pass between the Great Lakes and the Atlantic coast, and the decreasing supply of moisture from the Gulf is largely counteracted from these other sources and heavy rains may and generally do continue.

The storms that move up from the Tropics to the south Atlantic or Gulf coasts of the United States during the late summer or early autumn are termed "hurricanes." They are usually smaller in area than the storms which form on the continent, but are more intense and energetic. When first seen in the Tropics, they have a tendency to move slowly northwestward, and to continue in that direction until they reach the latitude of the Gulf coast, when they recurve to the northeast unless prevented from doing so by an area of high barometric pressure. On recurving they usually increase their rate of movement and sometimes sweep over our entire Atlantic coast in less than 48 hours.

When a hurricane makes its appearance in southern waters it is necessary to receive frequent reports from all observation points in its vicinity and watch its movements very closely in order to issue warnings ahead of it. Before the storm-warning system of the United States Weather Bureau was developed to its present high degree of efficiency these storms used to strew the Atlantic and Gulf coasts with the wrecks of vessels. Although the number of vessels

engaged in coastwise trade has increased considerably, the number of wrecks is but a small fraction of those of former times.



During the last few years the Weather Bureau has received reports by wireless telegraph from several cooperating vessels and its survey of the tropical regions has been much more complete than formerly.

XIII. WEATHER FORECASTING (CONTINUED).

Cold waves usually accompany energetic areas of high barometric pressure following those of low pressure. They are confined principally to the winter months, when temperature changes are most sudden and pronounced. If a rapid fall in temperature occurs in summer it is usually from a point much above the normal to a point as much below the normal without injurious conditions at any time, but in winter a fall from the freezing point to a temperature near zero would do much damage unless ample warnings were issued so as to allow the protection of perishable products.

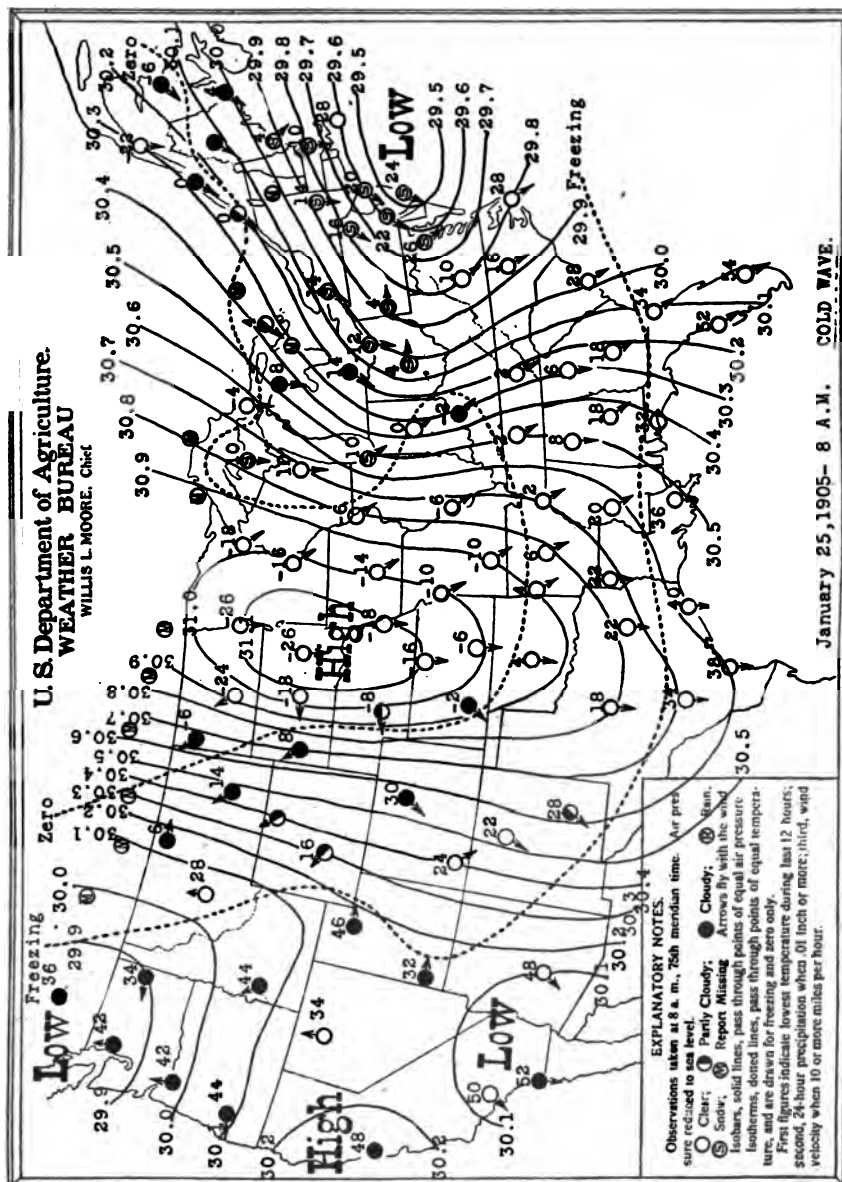
You have learned that the areas of high barometric pressure make their first appearance in the far northwest, usually over the northern Rocky Mountain plateau, and that they move either eastward across the Northern States or else southeastward to the lower Mississippi Valley, and then recurve to the eastward or northeastward. You have also learned that in these areas the air settles down cool and dry from the higher altitudes, or, more correctly speaking, the air settles down in the central portion of the area, while away from the central portion all the lower air currents have a slight deflection downward.

During the winter season, if a high pressure area appears in the far northwest, with a low area over the Southern States, the low area will usually move eastward and northeastward, while the high area, with its attendant low temperatures, will sweep southward to the Gulf coast. Should there be no well-defined area of low pressure over the Southern States, the high area would be more apt to pass eastward over the northerly route. A high-pressure area that is not preceded by a low will not cause so great a fall in temperature in proportion to its intensity as one that is thus preceded.

The high-pressure areas that move from the Northwest into the Southern States usually decrease in energy on recurving to the eastward or northeastward, and so reach the Atlantic States in a modified form that seldom causes a marked fall in temperature. When cold waves occur in the North Atlantic and New England States they follow closely upon the passage of a center of low pressure, the high-pressure area generally moving eastward or southeastward from the upper Lake region. Under certain conditions a cold wave may occur at the rear of a center of low pressure, with no well-defined high-pressure area following it, but in any event an increase in barometric pressure accompanies every cold wave.

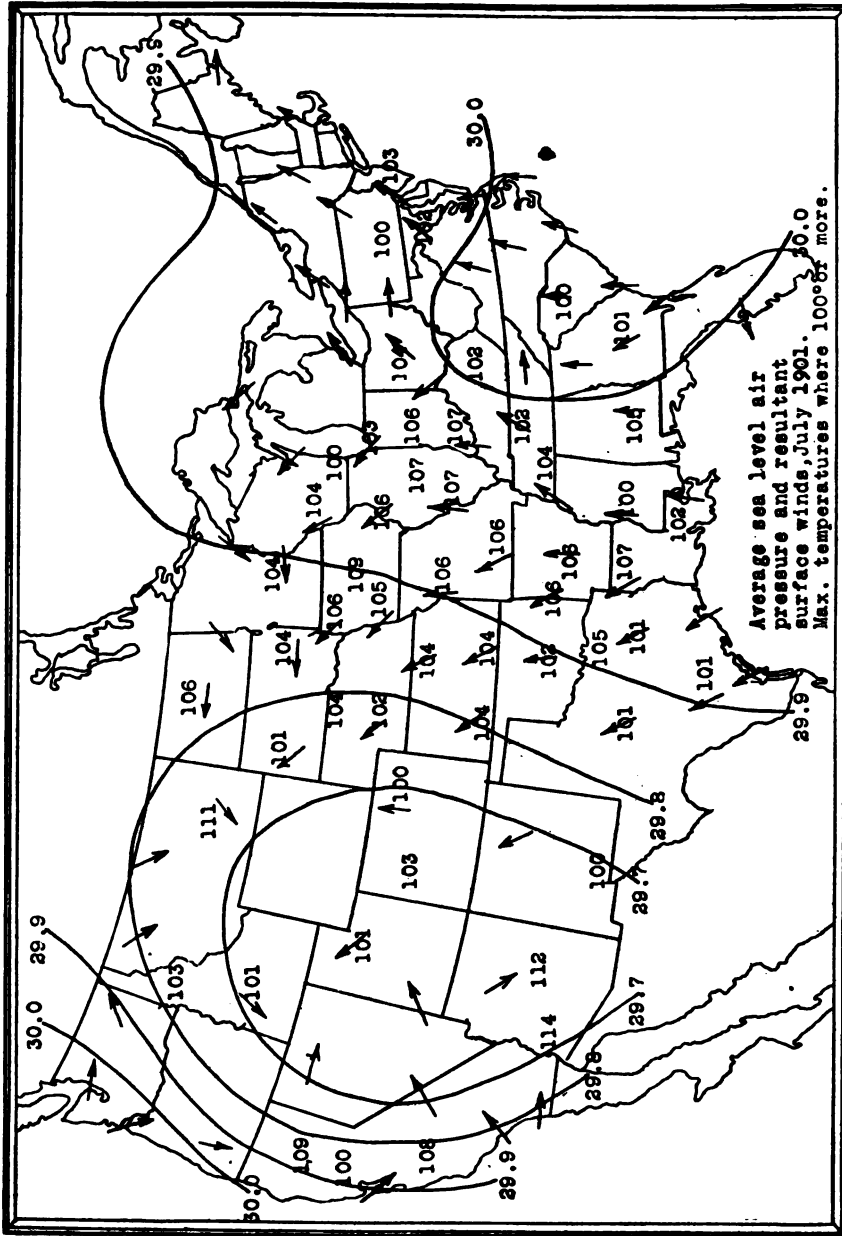
Mention has been made of the tendency of the air currents to flow from a crest of high pressure toward a center of low pressure, and it is therefore plain that when a cold area of high pressure is following a low from the Northwest the temperature will begin to fall at any

given place in its track as soon as the center of the low has passed eastward far enough to bring that place within the flow of air between the two centers.



Excessive heat is caused by barometric pressure gradients being practically the reverse of those in a cold wave, the high pressure being in the Southeast and the low pressure in the Northwest. During the summer season an area of only moderately high barometric

pressure will sometimes stagnate over the South Atlantic States or just off the coast, while a low moves into the upper Mississippi Valley and the upper Lake region. Under such conditions the air cur-



rents that flow from the central portion of the high area toward the low move along the surface and, steadily increasing in temperature, *they gather up moisture over their course and cause abnormally*

warm and humid conditions in the Ohio Basin and in the Middle and North Atlantic States. If the areas are large, with the crest of high pressure off the south Atlantic coast and the center of the low in the far Northwest, the abnormally high temperatures will cover all the great central valleys.

The month of July, 1901, marked the most intense period of abnormal heat from the Atlantic coast westward to the Rocky Mountains that has been recorded in the United States. The average barometric pressure for the month serves to illustrate the conditions that caused the intense heat much better than a map for any specific date, and a chart showing the average pressure for that period has been taken from the Monthly Weather Review and adapted to this purpose.

XIV. WEATHER FORECASTING (CONTINUED).

In our Northern States much the greater portion of the rainfall occurs on the eastern and southern sides of low-pressure areas. The heaviest rains in the Southern States are usually caused by low-pressure areas moving in from the Gulf, but rain often occurs when an area of high pressure moves down from the north, the cool descending air currents appearing to run under the moist lower air strata which are raised, cooled by expansion, and a portion of their moisture condensed and precipitated.

The areas of high and low barometric pressure are more energetic, excepting the West India hurricanes, and move across the country at a more rapid rate during the winter than during the summer season. The rate of movement of a storm area across the country should not be confused with the wind velocities within its boundaries, for sometimes a storm that is moving quite rapidly will be suddenly checked and will increase in energy as a consequence, thus developing higher wind velocities than when its movement of translation was greater. The West Indian hurricanes travel very slowly so long as they follow the westerly course, but the wind velocities generated within them are usually destructive.

The rate of movement of storm areas is seldom steady and uniform for any considerable length of time, but the average rate is about 37 miles per hour in winter and 22 miles per hour in summer. They travel faster across the Northern States than they do in the southern portion of the country.

High-pressure areas have a greater tendency to turn southward while crossing the great central valleys in the winter than they have during the summer. The larger and better formed all atmospheric disturbances are, the easier it becomes to anticipate their movements and developments and thereby to forecast ahead of them. It is when a map shows several partly developed areas, or when their movements become sluggish, that forecasting becomes most difficult.

So long as a disturbance keeps moving the forecaster has a basis for his calculations, but when it becomes stationary he has no means of determining when it will start to move again.

During midsummer when the pressure formations are least energetic there is a tendency for conditions to become localized, and we have showers instead of general rains. When conditions indicate showers a forecast must be made for them, and while they may cover much the greater portion of the territory for which they are forecast, still there will be many places where no rain will occur and where the forecaster will be blamed for missing his calculations.

When conditions are such as to indicate only a few widely scattered showers, the better policy will be to forecast fair weather, as that condition will no doubt prevail over three-fourths of the territory covered by the forecast. In those scattered localities where showers occur the forecaster will again be blamed for an unpardonable blunder.

In estimating the resultants of storm movements and developments it is necessary for the forecaster to estimate the intensity and effect of a great many forces, and to perform the work with great rapidity. He must be continually on the alert if he would make a high percentage of successes in his work.

XV. FORECASTING FROM LOCAL INDICATIONS.

The ability of mariners to forecast weather changes from local observation is proverbial. This is not because the signs are so much more pronounced over the ocean than over the land, but is primarily because the mariner has no other source of information and must learn to interpret their significance. On land a heavy storm is not so often a matter of life or death, and consequently while most people recognize a few weather signs they rarely follow them out in a systematic manner to determine their reliability.

About three-fourths of the population of our country can be readily reached with the information disseminated by the United States Weather Bureau by means of its publications, by the daily papers, and by telegraph and telephone. This advice being more reliable than local signs, has practically supplanted them in all the districts covered, and many lines of business and many social functions are planned and conducted accordingly.

Weather changes are not usually definitely heralded by local signs for a period longer than 12 hours in advance, while many local storms give scarcely an hour's notice of their coming. Very few indications apply with equal force to all parts of the country. Conditions along the Pacific coast differ materially from those along the Atlantic coast, the Gulf coast, or the interior of the continent, and in the interior there is a great difference between conditions in the Rocky

Mountain region and the central valleys or the Great Lakes. Many signs which might be considered reliable in the Ohio Valley would be valueless in the drier districts of the far Southwest.

In order that one may formulate a series of signs that will be distinctly applicable to the locality in which he lives he should proceed in a careful and systematic manner to record and correlate his observations. Weather proverbs will not be found to be generally applicable, and only those which when analyzed are found to be based on scientific fact will be worth considering.

Signs pertaining to the condition of the atmosphere, the appearance of the sky, the character and movements of the clouds, and the direction and force of the winds are, generally speaking, all that are worth testing out for one's particular locality.

Proverbs regarding the actions of birds and animals are usually of little value. Marked changes in the atmospheric conditions are responsible for their peculiar antics, and these same changes are generally preceded by reliable signs, if one learns to observe and interpret them.

Sayings which pertain to the moon and the planets are entirely foreign to the subject, and those which apply to forecasts for coming seasons are wholly without foundation. Reculiar growths and developments in vegetation are the result of weather conditions that have passed and have no connection with those to come. The character of the muskrat's house or the beaver's dam is the direct result of the stage of the water at the time the structures were made.

By mapping the entire Northern Hemisphere the Weather Bureau is enabled to forecast general conditions for a week or 10 days in advance with a creditable degree of accuracy, but at the present time there is nothing known which justifies any person in venturing forecasts for longer periods. Thus, the person who would learn to forecast from local observation will do well to confine his efforts to the detection of weather changes a few hours in advance. It is reasonable to expect a continuation of observed conditions at any time until there are indications of a decided change.

Inasmuch as the barometric pressure is the main feature of the weather map, and is of as much importance to the forecaster as all of the other information combined, it is equally as essential that the local observer should be equipped with some means by which to detect changes in atmospheric pressure. The pressure changes in connection with the wind direction will give him the key to the situation. There are certain wind-barometer indications that are applicable to all localities in our country, and the following statements are published on all Weather Bureau daily weather maps:

When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will

pass near or north of the observer within 12 to 24 hours, with wind shifting to northwest by way of south and southwest. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours, with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.

On account of its portability and ease of handling, an aneroid barometer is best suited to the needs of the local observer, and a reliable instrument can be purchased for \$10 to \$15. The legends, if any, on the face of the instrument should be entirely disregarded, remembering that even if at times they should seem to be applicable to a given locality, a change in altitude of a thousand feet would throw them to a decidedly different relative position on the scale.

The brass pointer should be set over the indicating hand on the dial of the instrument morning and evening and the change in atmospheric pressure noted for each 12-hour period. The barometer should be read and the wind direction and force noted when precipitation begins and again when it ends. The character and movements of the clouds should always be observed, as they are the only indicators of the conditions of the atmosphere at higher altitudes.

A series of such observations, when compared and classified, will soon reveal certain well-defined relations that will enable the observer to begin a list of reliable local signs. The list will increase with the period of observation, and established rules will be modified by noting the most common exceptions. Some signs which are reliable for one season of the year will need to be materially changed in order to apply to the conditions of a different time of the year. When a local sign has been thoroughly tested and found to be reliable in a large percentage of cases the observer should then record it permanently for the benefit of future generations in that locality. Each well-established rule will be of incalculable value to that community in times to come.

The observer should remember that all weather changes are the results of physical conditions occasioned by the unequal heating of the atmosphere and modified by the locality and the character of the surrounding territory. Everything savoring of astrology, of superstition, or of the mysterious in general should be entirely rejected, and he should proceed with his work on a purely physical and scientific basis.





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WEATHER BUREAU.—BULLETIN 43.

THE RIVERS AND FLOODS OF THE SACRAMENTO
AND SAN JOAQUIN WATERSHEDS.

Prepared under the direction of WILLIS L. MOORE, Chief U. S. Weather Bureau

BY

NATHANIEL R. TAYLOR,
LOCAL FORECASTER.



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LETTER OF TRANSMITTAL

UNITED STATES DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU, OFFICE OF THE CHIEF,
Washington, D. C., February 4, 1913.

The honorable the SECRETARY OF AGRICULTURE,
Washington, D. C.

SIR: I have the honor to transmit herewith a paper by Mr. Nathaniel R. Taylor, local forecaster in charge of the local office of the Weather Bureau at Sacramento, Cal., on "The Rivers and Floods in Sacramento and San Joaquin Watersheds."

I recommend the publication of this paper as a bulletin of the Weather Bureau.

Very respectfully,

H. E. WILLIAMS,
Acting Chief United States Weather Bureau.

Approved:

JAMES WILSON, *Secretary.*

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FIG. 1.—The Sacramento and San Joaquin watersheds.

THE RIVERS AND FLOODS OF THE SACRAMENTO AND SAN JOAQUIN WATERSHEDS.

By NATHANIEL R. TAYLOR, Local Forecaster.

INTRODUCTION.

This paper will be devoted to a discussion of some of the causes that modify stream flow in the Great Central Valley of California and to the tabulation of such river and rainfall data as are available in connection with flood periods, with notes on the various floods that have occurred since 1849, more especially those in the Sacramento watershed. A brief description of the larger streams and their watersheds will be given, together with distances between important points on the main rivers and their larger tributaries.

Much of the information relative to floods in the early days in the city of Sacramento has been gleaned from the History of Sacramento County, Cal., by Thompson and West, and by a perusal of the old files of the Sacramento newspapers, the Bee and the Record Union.

Information relative to the floods of the Feather and the Yuba Rivers, and to the condition of these streams during the past two decades, has been kindly furnished by Mr. W. T. Ellis, president of the Marysville Levee Commission, who has made an exhaustive study of floods in the watershed of the Feather-Yuba, and, who, more than any other official, is responsible for the almost impregnable levee system that has made Marysville practically immune from future floods.

Mr. W. E. Meek, of Antioch, Cal., and others, with whom the writer has discussed conditions in the island districts, have kindly supplied much valuable information, which has never before been published, relative to floods in the delta lands of the Sacramento and San Joaquin Rivers.

In addition to the records of the Weather Bureau, from which river and precipitation data have been taken, a study of the various Water-Supply Papers of the water resources branch of the United States Geological Survey has been the means of securing much of

the information regarding elevations and descriptions of stream sources in the high Sierra.

An article published in the American Society of Civil Engineers, by W. B. Clapp, E. C. Murphy, and W. F. Martin, has been of material assistance to the writer, especially with respect to the areas and capacities of the numerous flood basins of the Sacramento Valley.

The map, tabulations, and hydrographs printed in connection with this paper are the work of Mr. Hermann J. Andree, assistant observer, United States Weather Bureau.

While the records of the Weather Bureau contain river gauge readings at several points on the Sacramento River as early as 1875, and on the San Joaquin River since 1896, it was not until May, 1906, that a thorough river service was inaugurated, which included stations at all strategic points, not only on the Sacramento and San Joaquin Rivers but on all important watercourses that feed those streams.

The work of reorganizing the river service of the Great Central Valley was performed by Mr. James H. Scarr, local forecaster, United States Weather Bureau, under the direction of Prof. Willis L. Moore, chief of the bureau.

The length of the Great Central Valley of California is about 500 miles. It varies in width from a few miles at its northern limits, near Redding, to 50 or 60 miles in the Sacramento Valley, to as much as 125 miles in parts of the San Joaquin Valley. It is bounded on the east by the Sierra Nevada and on the west by the Coast Range. These ranges meet on the north at Mount Shasta and again on the south, where they are connected by the Tehachapi cross range, the whole being shut in, except for a narrow opening in the Coast Range at San Francisco, through which its drainage reaches the Pacific.

Probably in no other part of the United States are river conditions so complicated as in the section under discussion, draining, as it does, many thousands of square miles of high mountains where heavy rains and melting snows feed innumerable streams, many of which often grow from innocent rivulets to raging torrents in a few hours' time.

The total area drained is something over 60,000 square miles, and the entire output of all waterways is borne to two trunk streams, the Sacramento and San Joaquin, that merge in Suisun Bay and finally reach the Pacific Ocean through Carquinez Strait, San Pablo and San Francisco Bays.

The table following is taken from Reports on the Control of Floods in the Sacramento Valley and the adjacent San Joaquin Valley, Cal., published in Document No. 81, Sixty-second Congress, first session, and shows the magnitude of the maximum flood discharge of the Sacramento River, as compared with that of several well-known rivers of the United States.

	Drainage area above station (square miles).	Maximum flood dis- charge (cubic feet per second recorded).
Mississippi at Vicksburg.....	1,100,000	1,777,000
Mississippi above Missouri River.....	165,000	366,000
Missouri.....	527,000	546,000
Columbia.....	237,000	1,390,000
Ohio.....	201,700	1,233,000
Arkansas.....	186,300	440,000
Red River.....	90,000	210,000
Sacramento.....	26,000	1,600,000

¹ Estimated, 1907-1909.

The point brought out in the above table is that if the Mississippi had the same discharge per square mile as that of the Sacramento its maximum flood discharge would exceed 25,000,000 cubic feet per second. At this rate it would require only a short period of maximum flood discharge to convert the Mississippi Valley from Vicksburg to St. Louis into an inland sea of considerable depth.

While the great valley of California is one continuous area it is popularly known as two separate valleys—the Sacramento on the north and the San Joaquin on the south. These valleys meet at a point contiguous to the Mokelumne and Cosumnes Rivers, and their drainage, as has been stated, finds a common outlet to the sea.

At one time the Mokelumne River connected with the Sacramento River through Tyler Slough at Walnut Grove and Tyler emptied into the Sacramento at its junction with Georgiana Slough. Tyler Slough now being dammed causes all of the water of the Mokelumne and Cosumnes Rivers to flow into the San Joaquin. Therefore, the dividing line between the drainage area of the Sacramento and San Joaquin Valleys is formed by artificial levees that have been thrown up by reclamation districts.

River and flood conditions in the two valleys being somewhat dissimilar, they will be separately discussed in this paper.

THE SACRAMENTO VALLEY.

The Sacramento drainage basin extends from Mount Shasta southward to Suisun Bay and from the Trinity Mountains and the Coast Range eastward to the Sierra Nevada. The floor of the Sacramento Valley may be said to begin at about Redding, where its width is only a few miles, and to extend southward for a distance of about 150 miles. Above Redding the valley narrows rapidly and becomes a canyon. It widens as the city of Sacramento is approached, being somewhat over 50 miles at its widest point. The level part of the valley comprises an area of some 4,600 square miles. That part included between the summits of the abutting

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mountains comprises about 19,000 square miles, or nearly 13,000,000 acres.

The eastern watershed of the Sacramento Valley ranges in elevation from 10,000 feet in the south to 6,000 or 7,000 feet in the north. The western watershed ranges from 4,000 feet in the south to 9,000 feet in the north, and the northern watershed from 4,000 to 8,000 feet, exclusive of Mount Shasta, which has an elevation of 14,380 feet. (Water-Supply Paper No. 251, U. S. Geological Survey.)

The mean annual precipitation in the Sacramento watershed increases with altitude and is greatest at about 5,000 feet. Beyond this elevation it decreases. It increases as the upper end of the valley is approached, being about 18 inches at Rio Vista, 20 inches at Sacramento city, 23 inches at Chico, 25 inches at Red Bluff, and 36 inches at Redding. There is a noticeable increase in the mean annual precipitation as the foothill sections are approached and a marked increase thence through the hills and up the flanks of the Sierras. (See figs. 2 and 3.)

In figure 2 the shaded columns indicate the annual precipitation in inches for the following points, viz:

Station.	Elevation.	Station.	Elevation.
	<i>Feet.</i>		<i>Feet.</i>
No. 1. Sacramento.....	71	No. 10. Auburn.....	1,360
No. 2. Palermo.....	213	No. 11. Dunsmuir.....	2,285
No. 3. Red Bluff.....	307	No. 12. Colfax.....	2,421
No. 4. Redding.....	552	No. 13. Nevada City.....	2,530
No. 5. Fruto.....	624	No. 14. Grass Valley.....	2,690
No. 6. Newcastle.....	970	No. 15. Edgewood.....	2,955
No. 7. Shasta.....	1,049	No. 16. Sisson.....	3,555
No. 8. Delta.....	1,138	No. 17. Bowmans Dam.....	5,500
No. 9. Upper Lake.....	1,350	No. 18. Summit.....	7,017

In 1909, 113.85 inches of precipitation occurred at Bowmans Dam and 114.85 inches at Delta. At Magalia, in Butte County, there were 150.62 inches in the same year.

In the diagram on page 14 the figures at the top of columns have the following significance:

- | | |
|-------------------------|--------------------------|
| 1 equals season 1906-7. | 4 equals season 1909-10. |
| 2 equals season 1907-8. | 5 equals season 1910-11. |
| 3 equals season 1908-9. | 6 equals season 1911-12. |

The year is divided into two fairly well-defined seasons—the dry and the wet. The dry season extends from May to October, inclusive, and the wet from November to April, inclusive. More than 75 per cent of the annual precipitation occurs during the four months ending with March. The precipitation that occurs in the floor of the valley, that is, south of Redding, is invariably in the form of rain. Above the 4,000-foot level it is mostly in the form of snow, although heavy snow sometimes falls at altitudes as low as 2,000 feet.

(In inches.)

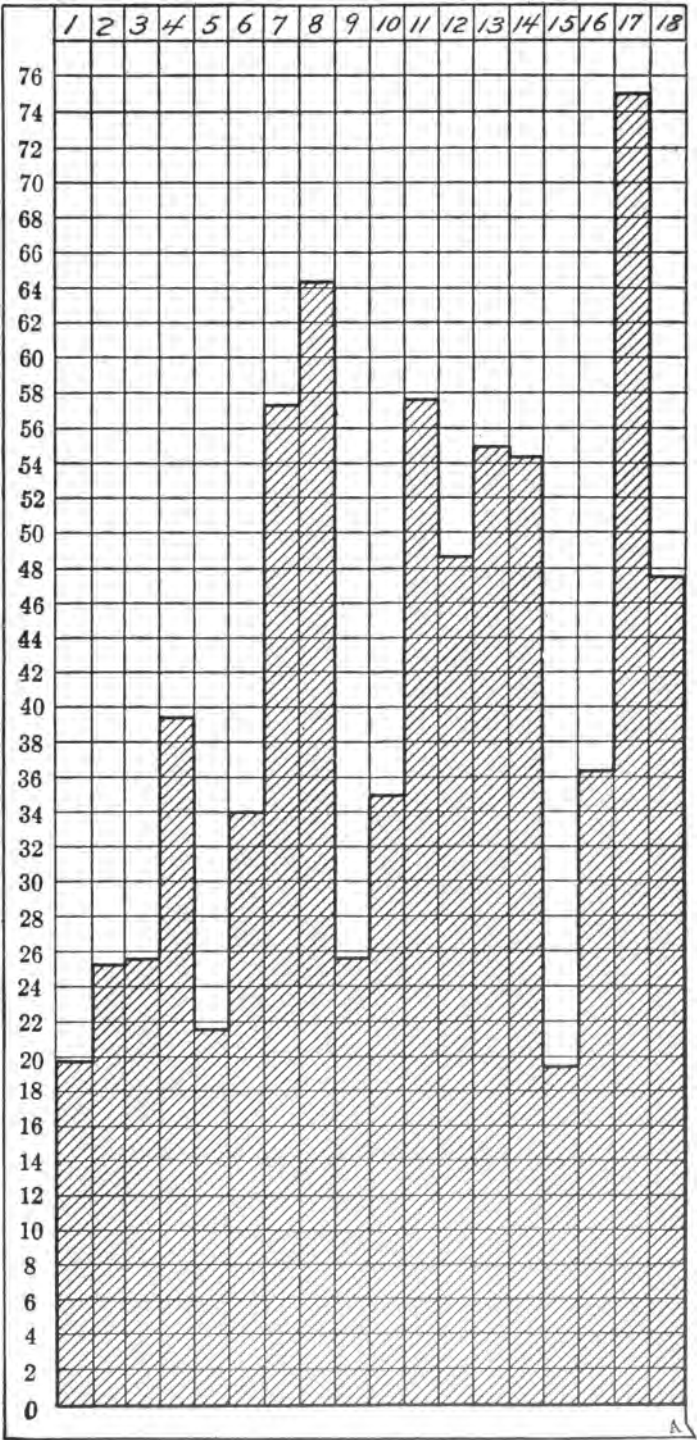


Fig. 2.—Normal annual precipitation at 18 stations in the Sacramento watershed

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In the report of the commissioner of public works in 1894 the total area of the Sacramento Valley is given as 4,250 square miles, 2,510 of which are described as highlands—that is, not subject to overflow; 450 square miles of lowlands overflowed occasionally by high floods; and 1,250 square miles of lowlands overflowed periodically. The above figures are, of course, now subject to revision on account of the fact that many of the lowlands included in the report have been reclaimed, much of which are now practically immune from even the highest floods.

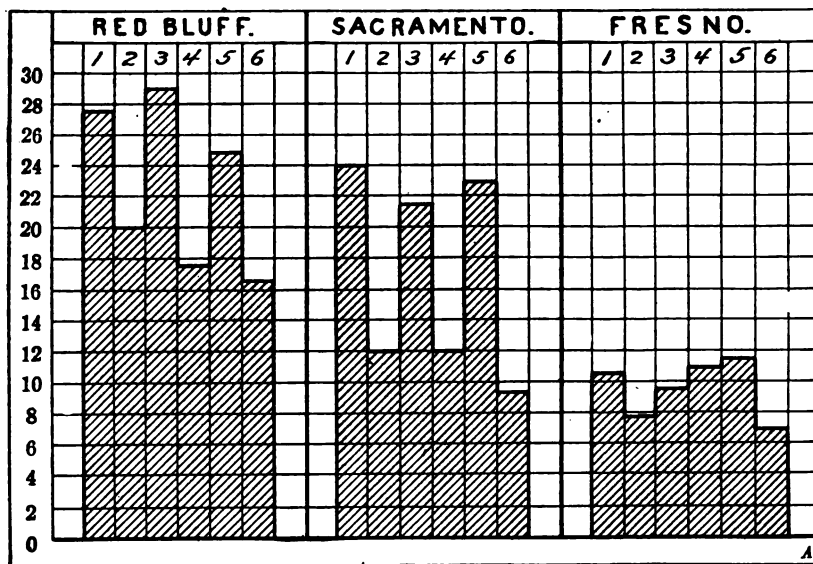


FIG. 3.—Seasonal precipitation at three stations in the central valleys for six seasons.

(In inches.)

THE SACRAMENTO RIVER.

The Sacramento River rises on the southwestern slopes of Mount Shasta and flows almost due south for a distance of about 370 miles, and discharges into Suisun Bay. It is navigable as far as Red Bluff, 265 miles from its mouth. It emerges from its rocky canyons a short distance above Redding, but is mostly confined within banks of sufficient height to carry its maximum flood discharge until a point a short distance below Red Bluff is reached; thence it flows through a practically level plain.

The lower course of the river for a distance of nearly 100 miles occupies a ridge from 5 to 20 feet higher than the troughs of the nearly parallel flood basins on each side, which are from 2 to 7 miles from the river.

RIVER STATIONS ON THE SACRAMENTO.

The river service on the Sacramento River now embraces seven regular river and rainfall stations, where gage readings are taken

daily the year round. During the seven months ending with May, river stages and 24-hour precipitation are telegraphed daily at 7 a. m., and oftener, should floods be imminent, or in progress, to the river center at Sacramento. In addition to the stations named, special stations are maintained at Dunsmuir and Sisson, from which reports of heavy rains are wired.

The following are the regular river and rainfall stations named, from north to south: Kennett, Red Bluff, Jacinto, Colusa, Knights Landing, Sacramento, and Rio Vista. The numerical values of highest, lowest, and mean stages of the rivers for each month and the year follow in a series of tables, and the same values are presented graphically in figures 4 to 14, inclusive.

Mean monthly river stages, Sacramento system.

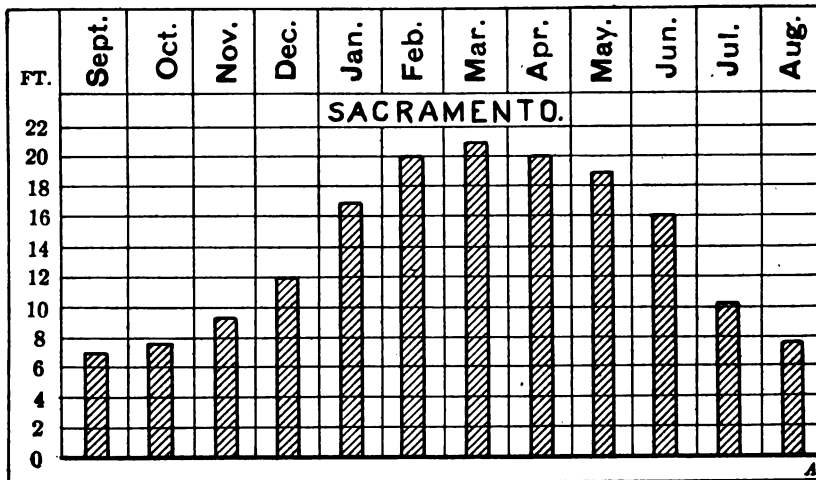


FIG. 4.—Mean monthly river stages.

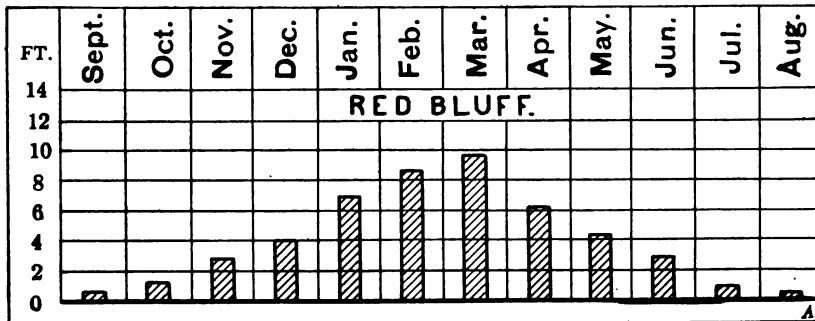


FIG. 4a.—Mean monthly river stages.

Mean monthly river stages, Sacramento system—Continued.

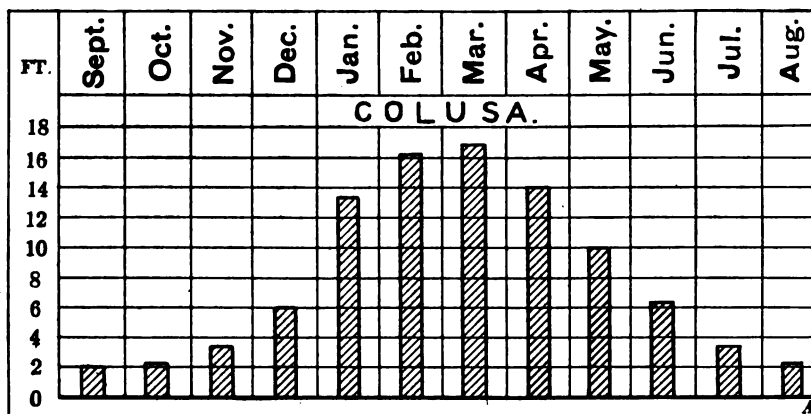


FIG. 4b.—Mean monthly river stages.

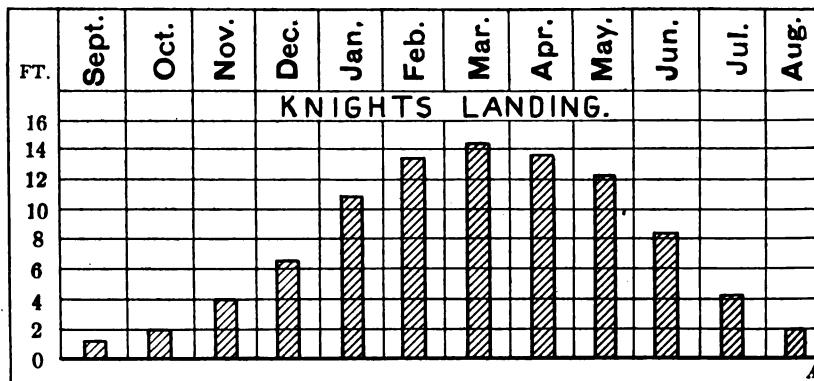
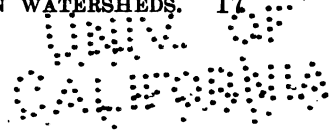


FIG. 4c.—Mean monthly river stages.



Mean monthly river stages, Sacramento system, Sacramento, Cal.—Continued.

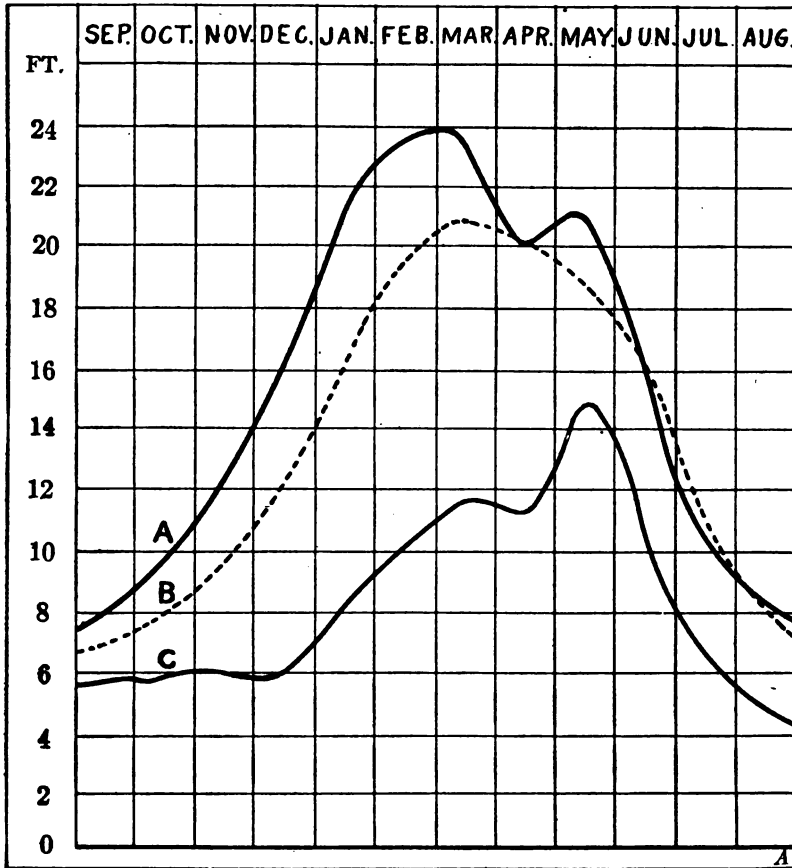


FIG. 5.—Mean monthly river stages. A, season 1900-1901 high water; B, mean stage 12 years; C, low-water season, 1911-12.

Highest, lowest, and mean seasonal stages, Sacramento River system.

(In feet.)

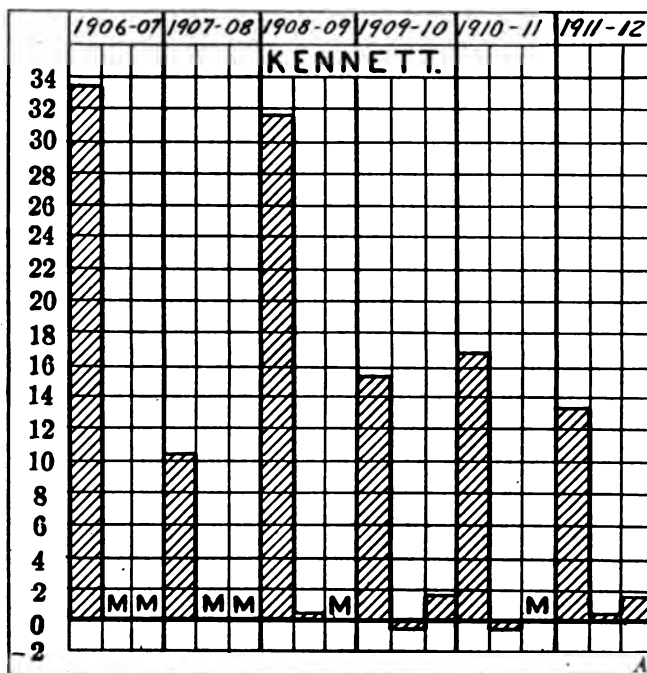


FIG. 6.—Highest, lowest, and mean stages.

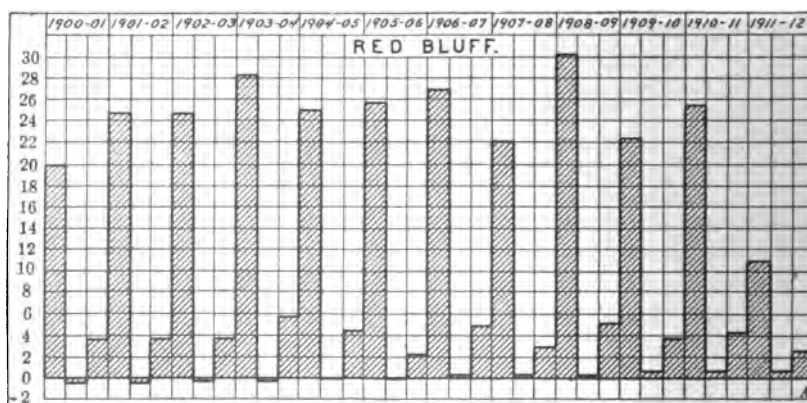
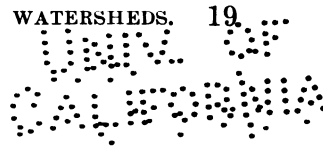


FIG. 7.—Highest, lowest, and mean stages. M—Missing.



Highest, lowest, and mean seasonal stages, Sacramento River system—Continued.

(In feet.)

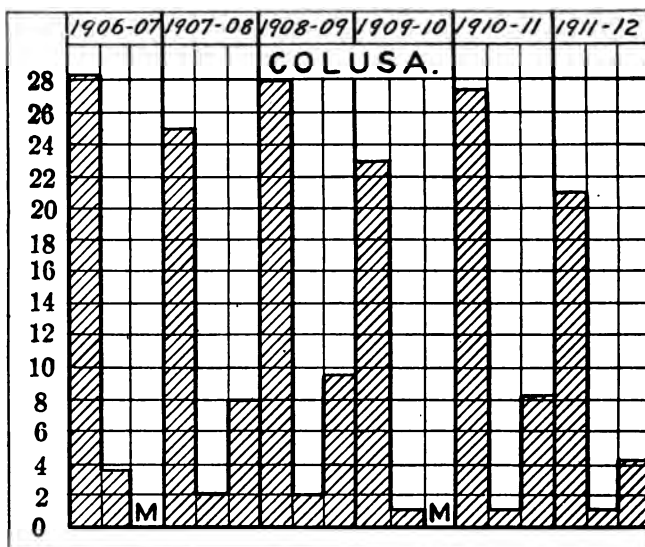


FIG. 8.—Highest, lowest, and mean stages.

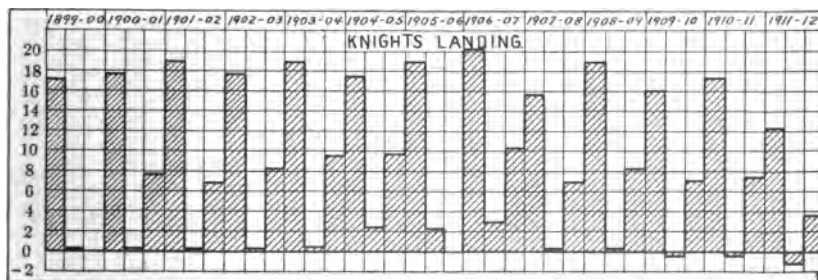


FIG. 9.—Highest, lowest, and mean stages.

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Highest, lowest, and mean seasonal stages, Sacramento River system—Continued.
(In feet.)

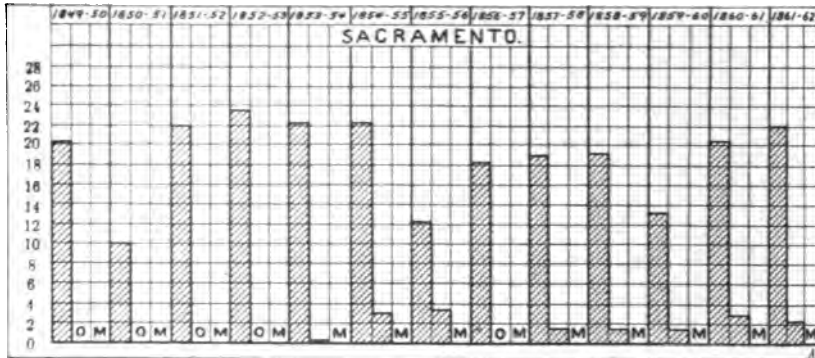


FIG. 10.—Highest, lowest, and mean stages.

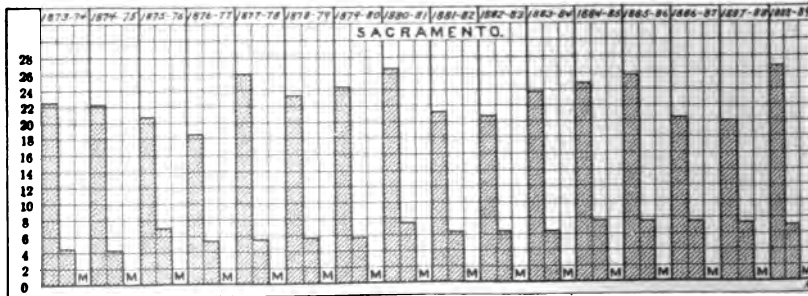
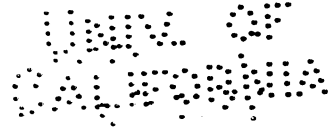


FIG. 10a.—Highest, lowest, and mean stages.



Highest, lowest, and mean seasonal stages, Sacramento River system—Continued.

(In feet.)

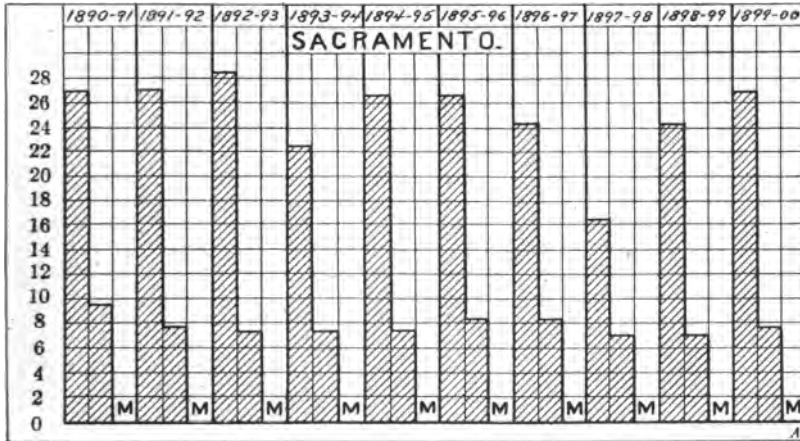


FIG. 11.—Highest, lowest, and mean stages.

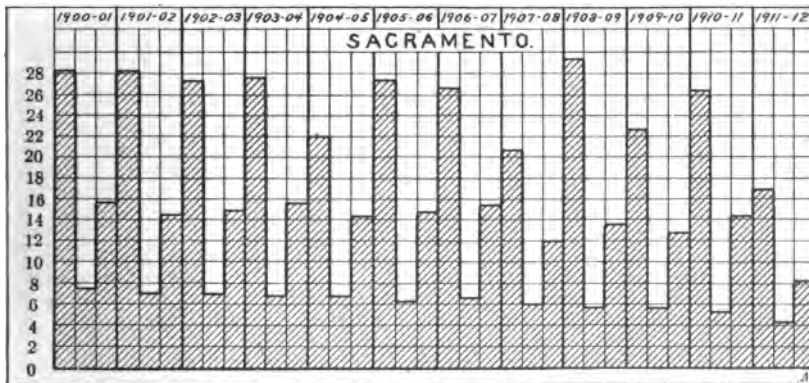


FIG. 11a.—Highest, lowest, and mean stages.

Highest, lowest, and mean seasonal stages, Sacramento River system—Continued.
(In feet.)

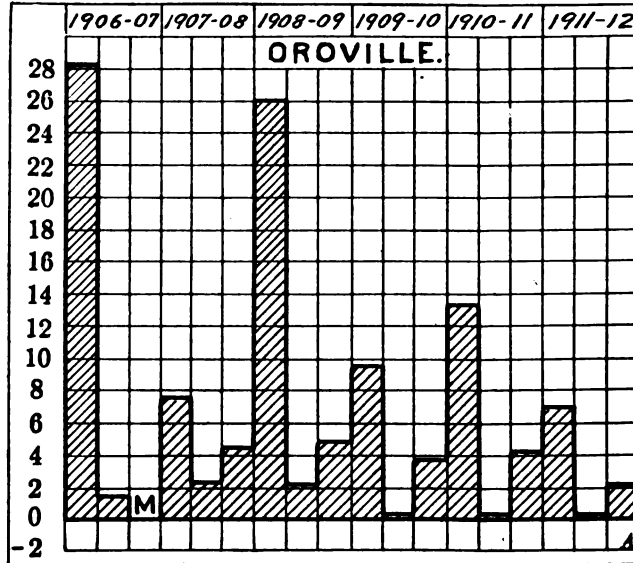


FIG. 12.—Highest, lowest, and mean stages.

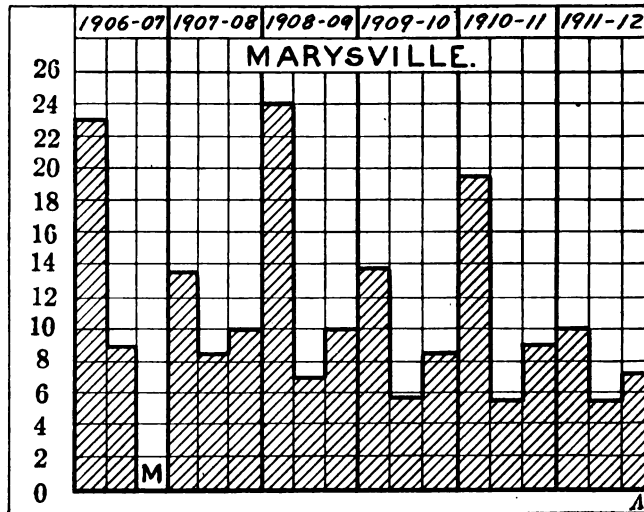


FIG. 13.—Highest, lowest, and mean stages.

Highest, lowest, and mean seasonal stages, Sacramento River system—Continued.

[Highest only for Marysville, 1862-1906.]

(In feet.)

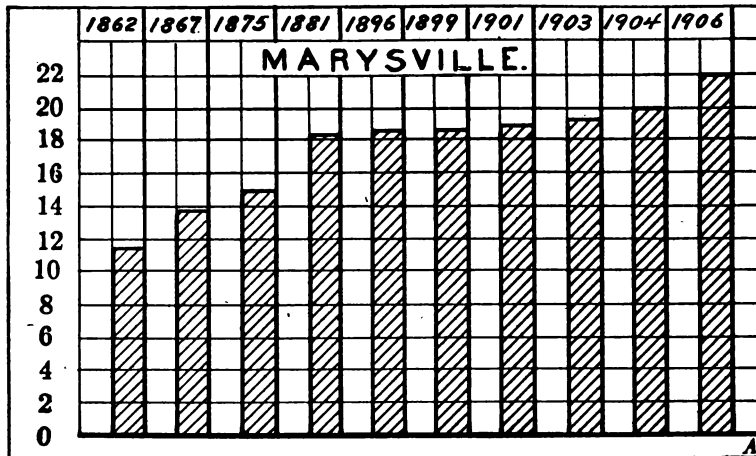


FIG. 13b.—Highest stages.

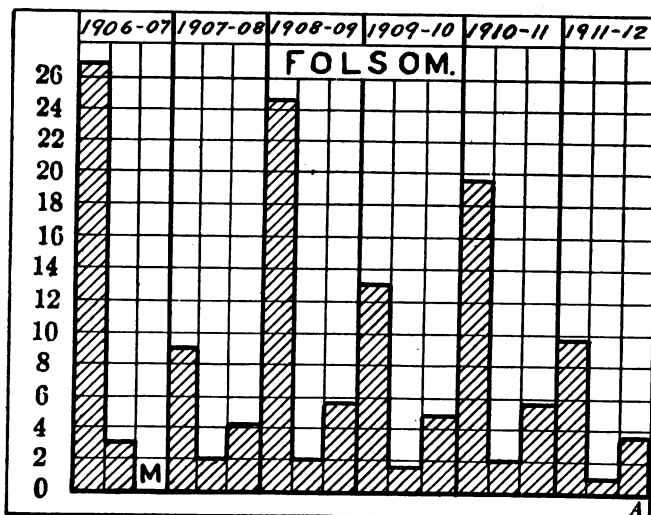


FIG. 14.—Highest, lowest, and mean stages.

TABLE NO. 2.—*Highest, lowest, and mean stages for each month and the mean for each year at Red Bluff.*

Stages in bold-face type indicate the extremes for each year.

Red Bluff is on the Sacramento River, 265 miles from its mouth. Elevation, 236 feet; flood stage, 23 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1899-1900.																		
1900-1.	1.3	-0.5	-0.3	8.0	-0.5	1.5	7.3	0.4	2.4	17.0	3.1	6.8	24.7	2.7	9.4	7.7	1.8	3.4
1901-2.	0.4	-1.1	-1.3	2.0	-1.1	0.8	12.3	-	2.0	17.3	2.5	4.5	12.4	4.3	8.1	20.1	4.3	8.9
1902-3.	0.2	-1.1	-1.2	4.0	-1.1	1.3	23.3	0.5	5.9	12.4	2.5	3.8	24.7	1.8	6.8	24.7	4.2	13.8
1903-4.	5.7	-0.3	-0.3	1.2	-	4.2	24.5	1.9	7.5	13.4	2.4	3.8	24.2	2.3	8.8	23.2	3.4	12.0
1904-5.	5.7	-0.3	-0.3	17.4	0.4	4.2	3.3	1.3	3.2	16.0	3.6	5.7	24.9	2.3	8.3	13.3	2.9	6.6
1905-6.	5.2	-0.2	-0.3	2.2	0.2	3.3	3.2	0.3	0.8	17.3	0.6	4.2	24.6	2.3	8.3	13.0	2.9	6.6
1906-7.	1.2	-0.5	-0.5	1.8	0.9	1.1	3.7	0.8	1.1	12.0	1.0	3.2	16.5	3.0	6.8	24.6	3.9	17.7
1907-8.	1.8	1.6	1.6	3.0	0.6	1.0	3.7	1.8	1.4	2.9	1.0	1.9	27.9	1.8	16.4	30.1	9.4	15.8
1908-9.	1.8	1.6	1.6	2.4	1.3	1.5	12.7	1.6	3.9	23.4	2.9	5.1	18.5	2.9	16.4	30.1	9.4	15.8
1909-10.	1.1	1.0	1.0	1.8	1.0	1.1	5.8	1.0	1.7	2.0	1.8	3.4	18.5	1.0	5.3	15.5	3.7	8.0
1910-11.	1.4	1.2	1.2	1.4	1.3	1.3	1.4	1.3	1.4	1.0	1.4	1.4	17.8	1.3	5.3	15.5	3.7	8.0
1911-12.																		
1899-1912.	5.7	-0.5	0.5	17.4	-0.5	1.1	24.5	-0.1	2.6	22.4	0.6	4.0	27.9	0.6	6.8	30.1	0.6	8.7

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1899-1900.																			
1900-1.	23.2	2.9	6.3	6.6	3.3	4.8	3.8	1.4	2.5	-0.3	1.2	0.3	-0.5	-0.1	-0.4	-0.5	-0.5	-0.5	3.6
1901-2.	12.4	4.2	7.4	6.5	3.2	3.7	5.3	2.2	3.1	1.2	2.0	1.2	-1.3	-1.3	0.6	-1.3	-2.2	-2.2	3.7
1902-3.	16.6	4.7	9.3	6.4	4.4	4.9	4.4	2.6	4.0	1.5	3.6	2.3	0.2	0.2	0.3	0.2	0.1	0.1	3.6
1903-4.	19.8	5.2	11.8	11.8	4.1	6.0	4.0	1.8	3.0	1.6	3.6	4.7	0.2	0.2	1.2	0.2	0.1	0.1	3.6
1904-5.	26.3	10.4	17.8	11.4	8.6	10.2	10.2	1.5	3.0	3.8	5.5	4.7	0.5	0.5	1.9	0.5	0.4	0.4	5.9
1905-6.	20.0	5.0	10.6	10.6	4.0	5.9	6.3	3.0	3.9	3.0	3.0	2.4	0.4	0.4	2.2	0.4	0.3	0.3	4.6
1906-7.	25.5	6.4	11.9	12.5	6.0	8.5	14.8	3.4	6.2	10.8	10.8	5.9	1.4	1.4	2.2	1.4	1.2	1.2	4.1
1907-8.	24.8	7.7	13.8	14.0	6.5	10.1	6.3	4.0	5.1	2.7	2.7	3.4	1.5	1.5	2.1	1.5	1.2	1.2	5.1
1908-9.	6.7	3.8	5.2	4.9	3.3	3.9	6.7	3.6	4.7	1.9	1.9	2.4	1.8	1.8	1.4	1.8	1.3	1.3	3.2
1909-10.	12.8	6.8	8.4	7.8	5.9	6.6	5.9	3.8	4.7	3.1	3.0	3.1	1.5	1.5	1.8	1.5	1.0	1.0	3.8
1910-11.	15.2	6.5	9.4	7.3	4.0	5.5	4.3	3.2	4.1	2.4	2.4	3.0	1.0	1.0	1.8	1.0	1.0	1.0	3.8
1911-12.	25.5	3.6	10.2	15.0	6.1	8.3	7.3	4.7	5.6	2.4	2.4	3.1	1.4	1.4	1.9	1.5	1.2	1.2	4.3
1899-1912.	10.8	2.4	5.2	9.1	3.1	4.0	6.6	3.8	5.6	2.0	2.0	3.1	1.2	1.2	1.6	1.2	1.0	1.0	2.7
1899-1912.	26.8	2.4	9.5	25.5	3.1	6.4	14.8	1.4	4.4	-0.3	10.8	2.7	-0.5	-0.5	1.2	1.5	-0.5	-0.5	4.2

TABLE No. 4.—*Highest, lowest, and mean stages for each month and the mean for each year at Colusa.*

Stages in bold-face type indicate the extremes for each year.

Colusa is on the Sacramento River, 156 miles from its mouth and 57 miles above Sacramento. Elevation, 36.8 feet; flood stage, 29 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	3.7	3.3	3.5	4.1	3.3	3.5	4.5	3.6	3.8	21.3	3.7	7.3	25.1	7.4	16.4	28.2	16.1	22.1
1907-8.....	2.4	2.0	2.1	4.3	2.0	2.6	6.7	2.7	3.4	6.2	3.4	7.3	21.8	8.9	15.6	25.2	11.1	17.1
1908-9.....	2.7	2.0	2.1	.....	.....	.....	19.2	3.2	6.8	23.0	6.3	10.6	24.0	3.7	22.6	27.4	19.8	22.8
1909-10.....	1.5	1.0	1.2	2.4	1.2	1.4	6.3	1.4	2.3	11.4	3.2	5.9	21.8	6.4	10.6	23.2	9.7	12.8
1910-11.....	1.8	1.2	1.3	2.0	1.6	1.8	2.2	1.8	1.9	2.3	1.9	2.0	23.3	2.6	8.6	24.2	8.7	16.3
1911-12.....	3.7	1.0	2.0	4.3	1.2	2.3	19.2	1.4	3.6	23.0	1.9	6.0	21.2	2.1	5.6	9.8	4.9	6.7
1906-1912.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	28.0	2.1	13.2	28.2	4.9	16.3

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	28.6	18.6	22.4	22.0	10.8	15.8	19.8	15.4	10.8	11.8	7.5	9.6	7.2	4.8	5.9	4.8	3.7	4.1	.....
1907-8.....	14.8	10.3	12.8	17.5	13.5	15.5	12.8	10.6	7.6	7.3	4.3	5.8	4.2	2.6	3.4	2.6	2.0	2.3	8.0
1908-9.....	20.9	15.5	17.7	16.3	9.3	12.3	8.9	13.3	8.9	9.2	5.6	7.4	5.5	2.9	3.9	2.9	2.1	2.4	9.6
1909-10.....	23.0	13.6	18.1	16.3	8.9	12.3	4.6	8.9	4.6	4.5	2.4	3.3	2.4	1.4	1.9	1.4	1.0	1.1	.....
1910-11.....	27.4	8.6	19.3	22.0	13.2	16.7	14.1	10.1	12.0	10.6	5.2	8.2	5.1	2.6	3.7	2.6	1.3	1.9	8.1
1911-12.....	18.3	4.4	9.8	11.8	5.6	7.0	7.1	15.9	7.1	10.3	3.2	5.5	3.1	1.2	1.9	1.2	.7	.9	4.6
1906-1912.....	28.6	4.4	16.7	22.0	5.6	14.0	15.9	4.6	10.2	11.8	2.4	6.6	7.2	1.2	3.4	4.8	.7	2.1	7.6

TABLE NO. 5.—*Highest, lowest, and mean stages for each month and the mean for each year at Knights Landing.*

Stages in bold-face type indicate the extremes for each year.

Knights Landing is on the Sacramento River, 99 miles from its mouth and 33 miles above Sacramento. Elevation, 16.1 feet; flood stage, 18 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1899-1900.....	1.3	0.4	0.7	6.8	0.4	2.9	10.4	2.2	5.1	13.2	5.5	9.0	17.9	12.2	14.9	11.9	7.8	9.8
1900-1901.....	1.6	0.3	0.6	2.7	0.5	1.0	10.4	1.8	2.7	11.8	4.7	8.2	15.2	10.0	13.9	17.9	12.3	13.1
1901-2.....	1.3	0.6	0.9	2.0	0.5	1.4	13.4	1.8	8.7	13.7	6.8	11.0	17.7	11.2	14.2	18.2	12.1	12.7
1902-3.....	1.9	0.7	1.2	9.9	3.4	6.1	16.2	1.0	8.0	15.2	7.5	11.3	17.2	12.2	16.5	16.7	12.1	14.4
1903-4.....	6.3	2.8	3.6	9.9	3.4	6.1	16.2	5.2	5.8	12.9	5.4	4.1	17.5	12.1	15.6	13.1	16.7	13.7
1904-5.....	4.6	2.2	3.3	2.3	2.2	2.2	6.3	3.0	3.9	16.3	2.8	3.4	16.5	13.5	15.3	18.8	14.9	16.3
1905-6.....	2.6	3.5	3.9	2.3	2.2	2.2	6.3	3.0	3.9	16.3	2.8	3.4	16.5	13.5	15.3	18.8	14.9	16.3
1906-7.....	3.3	2.4	2.8	2.8	2.0	2.2	3.4	2.5	2.7	12.5	2.6	5.9	15.0	2.5	12.3	18.7	10.9	14.0
1907-8.....	3.3	2.4	2.8	2.8	2.0	2.2	3.4	2.5	2.7	12.5	2.6	5.9	15.0	2.5	12.3	18.7	10.9	14.0
1908-9.....	6.6	2.2	4.8	3.0	2.2	1.1	5.4	1.2	2.0	5.0	7.2	11.5	14.2	7.7	10.7	14.7	10.6	12.4
1909-10.....	1.2	0.4	0.8	2.4	1.0	1.5	13.3	2.2	5.5	15.1	7.2	11.5	14.2	7.7	10.7	14.7	10.6	12.4
1910-11.....	5.5	0.4	1.1	1.0	0.0	0.3	5.8	1.4	1.2	10.7	2.5	5.3	14.2	1.7	7.4	17.2	10.4	15.0
1911-12.....	5.5	0.4	1.1	1.0	0.0	0.3	5.8	1.4	1.2	10.7	2.5	5.3	14.2	1.7	7.4	17.2	10.4	15.0
1899-1912.....	6.3	0.4	1.4	9.9	0.0	2.0	16.2	2.2	4.1	16.3	6.0	6.8	19.1	7.0	11.0	19.2	3.4	13.5

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1899-1900.....	16.0	12.5	13.5	12.2	9.8	11.3	10.8	10.2	9.7	7.4	3.3	5.3	3.2	1.0	1.9	1.0	0.5	0.7	7.7
1900-1901.....	17.2	12.2	14.5	11.9	10.0	10.6	13.8	10.2	11.6	10.0	4.0	6.6	1.2	2.4	2.4	1.7	0.8	0.8	7.1
1901-2.....	18.4	12.0	14.7	14.7	11.2	13.4	13.8	11.8	12.8	11.9	5.8	9.0	3.8	2.9	4.0	3.1	2.2	2.1	8.2
1902-3.....	18.4	12.4	14.4	16.9	13.0	15.0	12.9	8.8	11.2	8.8	3.8	6.3	2.9	2.7	2.6	1.6	0.9	1.1	9.4
1903-4.....	19.0	16.7	17.4	17.2	15.8	16.3	15.8	14.4	15.4	14.2	7.9	11.3	7.8	4.2	5.8	5.2	3.9	4.2	9.5
1904-5.....	17.4	13.4	15.7	17.2	13.8	15.4	14.3	12.0	13.1	11.9	7.0	9.7	6.8	3.9	5.3	3.9	3.2	3.2	9.5
1905-6.....	20.2	15.6	16.6	18.9	15.8	16.8	16.7	13.2	15.4	16.8	13.3	15.6	13.0	6.0	8.2	6.0	4.7	4.5	10.4
1906-7.....	12.6	10.7	11.9	17.2	15.9	16.7	15.7	13.7	14.8	13.6	10.8	12.6	10.6	6.0	8.2	6.0	3.4	4.8	8.7
1907-8.....	17.5	15.4	16.5	14.3	8.8	10.1	10.5	8.6	9.4	8.4	3.9	6.2	3.9	1.4	2.4	1.3	0.6	0.6	7.1
1908-9.....	16.1	14.3	15.3	15.3	14.3	14.8	14.2	11.6	13.1	11.5	7.6	9.9	7.5	3.5	5.9	3.2	2.1	2.1	8.4
1909-10.....	17.5	10.0	15.3	16.5	12.2	15.7	11.8	5.4	8.7	5.3	2.2	3.4	2.1	1.2	1.5	0.4	0.2	0.2	7.2
1910-11.....	11.1	3.6	8.1	9.7	5.1	6.3	11.4	6.8	9.5	10.8	2.6	5.8	2.4	2.2	4.7	2.1	1.0	1.0	7.6
1911-12.....	20.2	3.6	14.5	18.9	5.1	13.7	16.7	6.8	12.2	16.8	2.2	8.7	13.0	0.3	4.1	8.2	1.2	1.2	3.9
1899-1912.....	20.2	3.6	14.5	18.9	5.1	13.7	16.7	6.8	12.2	16.8	2.2	8.7	13.0	0.3	4.1	8.2	1.2	1.2	7.8

TABLE NO. 6.—*Highest, lowest, and mean stages for each month and the mean for each year at Sacramento.*

Stages in bold-face type indicate the extremes for each year.

Sacramento is on the Sacramento River, 64 miles above Suisun Bay and 38 miles above Rio Vista. Elevation, —0.5 foot; flood stage, 29 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1889-1900.....	7.9	7.6	7.8	13.5	7.6	9.5	19.5	8.8	12.0	19.5	12.0	15.2	27.0	21.7	24.4	21.4	15.5	17.9
1900-1.....	8.5	7.2	7.6	10.7	7.6	8.2	14.6	8.1	9.4	20.5	11.6	15.4	22.7	16.0	21.5	23.2	21.0	23.5
1901-2.....	7.9	7.2	7.5	10.3	6.9	7.7	16.9	8.1	13.1	9.4	18.1	12.6	12.0	9.8	10.8	27.6	9.8	18.8
1902-3.....	7.3	7.0	7.1	8.7	7.0	7.5	20.5	7.3	14.1	19.6	14.3	15.9	23.2	12.6	16.5	23.2	18.7	21.1
1903-4.....	12.0	8.2	9.1	18.0	9.2	11.7	12.0	10.4	11.0	17.0	10.8	11.7	15.8	13.3	14.4	27.9	12.8	19.2
1904-5.....	7.0	6.3	6.6	6.7	6.4	6.5	7.4	6.5	6.7	7.8	6.9	7.1	20.8	16.6	18.7	22.0	19.8	20.9
1905-6.....	8.8	7.6	8.0	7.6	6.8	7.1	10.3	7.0	8.0	20.5	7.3	12.5	23.0	7.0	15.2	21.5	16.1	18.7
1906-7.....	8.5	7.5	8.0	8.0	7.3	7.5	8.4	7.5	7.5	15.3	7.7	10.3	20.6	18.2	19.4	27.2	20.5	23.3
1907-8.....	5.6	5.3	5.5	8.3	5.3	5.9	9.3	5.8	6.6	9.6	6.8	7.5	29.6	7.2	15.9	24.0	16.4	18.9
1908-9.....	6.4	5.5	5.9	7.0	6.0	6.4	18.7	6.7	10.8	22.0	13.1	17.3	20.0	14.0	16.8	23.9	15.7	22.6
1909-10.....	6.3	5.1	5.5	6.2	5.3	5.7	9.4	5.7	6.5	14.0	7.4	9.5	28.4	6.9	14.3	26.9	17.5	22.8
1910-11.....	5.9	5.5	5.7	6.0	5.6	5.8	6.7	5.7	6.0	6.2	5.7	5.9	13.9	5.8	8.1	11.2	8.6	9.8
1911-12.....	12.0	5.1	7.0	18.0	5.3	7.5	20.5	5.7	9.3	22.0	5.7	12.1	29.6	5.8	16.7	28.2	8.6	19.8
1889-1912.....	23.5	17.4	21.5	22.0	18.5	20.3	19.4	16.5	16.1	11.0	13.3	10.8	8.3	10.8	8.3	7.7	7.9	7.9
1900-1.....	27.3	21.3	23.5	21.0	19.1	19.8	22.2	20.1	21.2	12.4	15.9	12.3	8.5	10.1	8.5	7.7	8.0	15.7
1901-2.....	28.2	20.5	23.3	22.4	20.0	21.4	21.8	20.8	20.2	13.6	18.1	13.3	9.6	11.0	9.7	7.9	8.6	14.5
1902-3.....	25.1	18.3	21.7	21.0	23.8	22.1	21.5	17.3	20.2	11.7	14.7	11.7	8.2	9.5	8.0	7.2	7.6	14.8
1903-4.....	26.3	21.8	24.2	24.0	20.8	22.1	20.5	21.3	20.9	15.8	18.8	15.6	10.5	12.6	10.3	9.0	9.7	15.7
1904-5.....	21.9	18.0	20.0	19.6	20.6	19.6	17.5	18.6	17.3	11.5	14.8	11.3	8.2	9.6	8.1	6.9	7.4	14.5
1905-6.....	26.1	20.9	22.9	27.4	21.4	23.6	22.2	20.5	22.9	20.5	17.8	12.0	11.7	16.3	12.0	8.8	10.4	14.8
1906-7.....	26.9	20.4	22.7	22.3	20.3	21.3	19.2	19.6	19.8	17.8	18.7	17.8	12.0	14.9	11.8	8.4	9.8	15.4
1907-8.....	17.5	15.8	16.8	17.2	15.2	16.3	17.1	15.3	16.2	9.9	12.6	9.7	7.8	7.8	6.6	5.6	6.0	12.0
1908-9.....	26.9	18.6	19.8	20.1	18.6	19.3	17.5	19.1	17.9	13.2	16.3	13.2	7.9	9.9	7.9	6.2	6.8	13.4
1909-10.....	22.8	19.0	21.0	20.2	20.9	20.9	19.9	12.5	16.4	7.4	9.4	7.1	5.8	6.5	6.2	5.3	5.6	12.9
1910-11.....	25.1	17.1	21.1	22.3	20.2	22.8	22.0	16.4	21.5	18.0	20.5	17.0	8.4	11.9	8.2	5.7	6.8	14.2
1911-12.....	13.9	8.4	11.5	12.0	10.2	11.2	16.7	12.2	16.3	8.5	12.3	8.3	5.2	6.4	5.4	4.1	4.7	8.5
1889-1912.....	28.2	8.4	20.7	27.6	10.2	20.2	22.2	12.2	22.9	7.4	16.0	20.5	5.2	10.4	12.0	4.1	7.6	13.9

TABLE No. 7.—*Highest, lowest, and mean stages for each month and the mean for each year at Oroville.*

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
	Stages in bold-face type indicate the extremes for each year.																	
1906-7.....	3.8	3.6	3.7	3.5	3.3	3.6	3.7	3.5	3.6	7.8	3.5	4.6	7.7	1.4	3.1	17.6	6.3	8.9
1907-8.....	3.8	3.6	3.7	3.7	3.3	3.6	4.3	3.5	3.9	7.8	3.5	4.6	7.7	4.3	5.6	6.7	4.4	5.0
1908-9.....	2.2	2.3	2.3	3.0	2.3	2.6	2.4	2.4	2.9	5.0	2.8	3.1	26.0	2.8	11.0	9.9	7.1	8.0
1909-10.....	2.2	1.0	1.4	3.6	1.7	1.7	9.7	2.0	3.9	11.0	3.7	5.4	16.7	3.9	4.9	8.2	4.6	5.2
1910-11.....	1.4	1.5	1.9	1.9	1.9	1.9	5.4	7.7	1.5	6.7	1.8	2.9	13.3	1.5	4.1	9.6	4.0	5.6
1911-12.....	1.3	.9	1.0	1.5	.8	1.1	2.3	.7	1.4	1.5	.9	1.2	7.1	1.3	2.7	3.2	2.0	2.5
1906-1912.....	3.8	.5	1.9	5.0	.5	2.0	9.7	.7	2.6	11.0	.9	3.4	26.0	1.3	5.2	17.6	2.0	5.9

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
	Stages in bold-face type indicate the extremes for each year.																		
1906-7.....	23.2	5.1	10.9	12.7	10.1	10.9	8.8	8.8	9.4	6.4	7.7	6.3	4.6	5.2	4.5	3.8	2.4	4.0	4.6
1907-8.....	7.0	4.7	5.8	7.4	5.6	6.6	6.9	5.7	6.2	5.7	4.9	3.8	2.8	3.2	2.8	2.4	2.5	2.5	4.6
1908-9.....	9.0	6.4	7.1	8.8	6.5	7.5	8.2	6.5	7.2	7.0	4.5	4.3	2.3	3.1	2.2	1.5	1.8	1.8	5.2
1909-10.....	9.0	6.4	7.4	7.0	5.9	6.6	6.0	3.4	4.9	3.2	1.7	1.7	2.8	1.2	1.0	1.6	1.8	3.8	4.3
1910-11.....	10.2	4.1	6.8	12.4	7.0	8.9	9.1	7.4	8.0	8.1	5.0	4.9	2.0	3.3	2.0	1.0	1.5	4.3	4.3
1911-12.....	6.1	1.9	3.5	5.1	2.8	3.6	5.9	5.0	5.4	1.4	3.5	1.6	.5	.9	.8	.6	.4	.4	2.3
1906-1912.....	28.2	1.9	6.9	12.7	2.8	7.4	10.0	3.4	6.8	9.0	1.4	5.2	6.3	.5	2.8	.0	1.8	4.0	4.0

Stages in bold-face type indicate the extremes for each year.

Oroville is on the Feather River, 32 miles above its junction with the Yuba at Marysville, and 76 miles above Sacramento. Elevation, 147.4 feet; flood stage, 25 feet.

TABLE No. 8.—*Highest, lowest, and mean stages for each month and the mean for each year at Marysville.*

Stages in bold-face type indicate the extremes for each year.

Marysville is on the Yuba River at its junction with the Feather River, 44 miles above Sacramento. Elevation, 46.8 feet; flood stage, 28 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	9.1	8.9	9.0	8.7	8.3	8.5	8.6	8.5	8.6	13.1	8.5	9.6	14.7	10.8	11.7	21.9	12.7	14.5
1907-8.....	8.5	8.3	8.4	10.3	8.3	8.5	8.7	8.5	8.6	10.2	8.6	8.9	13.4	9.4	10.7	12.7	9.8	10.5
1908-9.....	6.7	6.3	6.5	7.5	6.2	6.6	14.0	6.9	8.8	14.9	8.0	9.6	24.0	8.7	15.1	15.3	11.0	12.3
1909-10.....	7.1	5.8	6.0	6.4	5.7	5.6	7.4	5.8	6.2	9.4	6.2	6.9	12.4	8.6	9.6	10.9	8.8	9.4
1910-11.....	7.5	7.3	7.3	7.5	6.7	7.1	8.2	6.3	6.8	6.5	6.1	6.3	19.3	6.3	7.2	18.2	8.3	10.0
1911-12.....	9.1	5.8	7.4	10.3	5.7	7.3	14.0	5.8	7.8	14.9	6.1	8.3	24.0	6.1	10.6	21.9	6.7	10.6
1906-1912.....	23.3	6.7	11.0	16.0	7.2	11.4	14.2	8.8	11.3	6.9	10.3	11.9	5.8	8.3	9.8	5.5	7.3	9.0

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	23.3	12.7	14.6	15.7	13.6	14.6	14.2	13.1	13.6	14.0	11.8	12.7	11.9	9.9	10.8	9.8	9.2	9.3	.....
1907-8.....	11.6	10.3	10.9	12.5	10.4	11.4	12.9	11.0	11.8	11.3	9.7	10.6	9.7	8.8	9.2	8.8	8.5	8.6	10.0
1908-9.....	11.9	9.9	10.7	12.0	10.2	11.0	12.3	10.3	11.3	11.7	9.3	10.4	9.2	7.1	7.9	7.1	6.7	6.8	10.0
1909-10.....	13.9	10.3	11.2	11.5	10.7	11.1	10.7	8.8	9.7	8.9	7.0	7.7	6.9	6.2	6.5	6.2	5.8	6.0	8.6
1910-11.....	15.5	8.4	10.6	16.0	10.9	12.4	12.7	11.3	12.0	13.1	10.5	11.8	10.3	8.1	9.2	8.0	7.4	7.7	9.0
1911-12.....	9.8	6.7	7.9	9.5	7.2	7.8	10.0	8.8	9.5	10.1	6.9	8.4	6.8	5.8	6.1	5.8	5.5	5.6	7.3
1906-1912.....	23.3	6.7	11.0	16.0	7.2	11.4	14.2	8.8	11.3	14.0	6.9	10.3	11.9	5.8	8.3	9.8	5.5	7.3	9.0

TABLE NO. 9.—*Highest, lowest, and mean stages for each month and the mean for each year at Folsom.*

Stages in bold-face type indicate the extremes for each year.

Folsom is on the American River 24 miles from its mouth and 25 miles from Sacramento on the Sacramento River. Elevation, 110.6 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	3.1	3.0	3.0	3.2	2.5	2.9	3.1	2.7	2.9	8.0	2.7	3.9	9.8	3.4	4.6	19.9	6.0	8.5
1907-8.....	2.0	1.9	1.9	3.0	1.9	2.5	4.0	2.3	2.3	2.7	2.5	3.0	3.8	3.8	4.7	5.2	3.8	4.3
1908-9.....	2.0	1.7	1.8	3.0	1.8	2.2	15.2	2.8	4.9	13.6	4.0	6.6	14.5	2.7	10.8	13.5	7.0	8.9
1909-10.....	2.7	1.9	1.8	2.1	2.9	2.1	4.0	2.0	2.6	8.0	2.5	3.7	4.9	4.9	6.5	7.5	5.2	6.0
1910-11.....	2.0	.8	1.1	.8	.8	.8	2.9	1.4	2.3	2.5	2.1	2.3	5.4	2.4	7.8	14.3	5.1	7.4
1911-12.....	3.1	.8	2.0	5.0	.8	2.1	15.2	1.4	3.1	15.6	2.1	3.9	24.5	2.4	3.1	3.4	2.7	3.0
1906-1912.....	3.1	.8	2.0	5.0	.8	2.1	15.2	1.4	3.1	15.6	2.1	3.9	24.5	2.4	6.2	19.9	2.7	6.3

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	24.8	5.9	10.8	12.5	9.5	11.0	12.1	8.3	10.0	11.9	7.0	9.2	9.2	4.5	6.2	4.5	2.0	3.7	4.1
1907-8.....	6.3	4.2	5.3	4.8	3.9	4.3	6.7	5.1	6.0	3.6	4.1	4.9	4.1	2.2	3.2	2.7	1.9	2.2	4.1
1908-9.....	9.3	5.8	7.0	5.8	4.8	5.3	10.0	6.1	8.5	11.5	5.5	7.6	5.4	2.9	3.9	3.1	2.0	2.4	5.6
1909-10.....	12.9	7.1	8.5	10.5	7.0	8.7	8.4	5.4	6.6	3.4	4.1	3.4	4.1	2.1	2.5	2.0	1.9	1.9	5.0
1910-11.....	13.1	5.1	9.0	13.2	7.6	9.9	11.3	5.6	9.4	11.9	6.6	10.1	6.1	3.1	4.7	3.0	2.0	2.5	5.9
1911-12.....	6.3	2.8	4.0	7.7	4.1	4.7	9.3	5.9	7.4	9.6	3.9	6.0	3.8	2.3	2.9	2.3	1.4	1.8	3.3
1906-1912.....	26.8	2.8	7.4	13.2	4.1	8.7	12.1	5.1	8.0	11.9	3.4	7.0	9.2	2.1	3.9	4.5	1.4	2.4	4.8

Kennett is about 3 miles below the mouth of the Pit River and 323 miles above the mouth of the Sacramento. The drainage area above the station is 8,450 square miles. Besides the drainage of the elevated region of the Sacramento, this station also shows the output of the Pit. Kennett is really the starting point of all flood waves that affect the upper Sacramento River.

Red Bluff is 265 miles from the mouth of the River and 58 miles below Kennett. The drainage area above the station is 11,058 square miles. The average fall per mile between Kennett and Red Bluff is 6.6 feet. When the river at Red Bluff is at or near a 10-foot stage a 25-foot stage at Kennett will cause an additional rise at Red Bluff of 10 or 11 feet. It has been closely estimated that under these conditions the Kennett water will reach Red Bluff in between 13 and 14 hours.

Jacinto is 198 miles from the mouth of the river and 67 miles below Red Bluff. The drainage area above the station is about 14,000 square miles. The average fall per mile between Red Bluff and Jacinto is about 2.6 feet. The Red Bluff flood wave will usually reach Jacinto in about 20 hours, and a 10-foot stage at Jacinto will generally be augmented by about 6 feet from a 20-foot head at Red Bluff, eliminating, of course, the output of Stony Creek, which empties into the Sacramento 9 miles above Jacinto.

Colusa is 156 miles from the mouth of the river and 42 miles below Jacinto. The drainage area above the station is 15,943 square miles. The average fall per mile between Jacinto and Colusa is slightly over a foot. The Jacinto station has recently been established in the place of Monroeville, near the mouth of Stony Creek, which has been abandoned. The effect of Stony Creek flood discharge on the river at Jacinto and Colusa will be discussed in connection with the station at St. John on Stony Creek.

Knights Landing is 99 miles above the mouth of the river and 57 miles below Colusa. The drainage area above the station is 16,793 square miles. The average fall per mile between Colusa and Knights Landing is about 0.4 foot. The effect of high water at Colusa on points down the river depends altogether on the condition of the levees and on the amount of water in Colusa, Yolo, and Sutter Basins.

Sacramento City is at the junction of the Sacramento and American Rivers, and is 64 miles from the mouth of the river. It is 35 miles below Knights Landing and 20 miles below the mouth of the Feather River at Vernon. The drainage area above the station is 28,433 square miles. The average fall per mile between Knights Landing and Sacramento is about 0.5 of a foot.

Much of the flood waters of the Feather River escapes either into Sutter Basin or through breaks on the west side into Yolo Basin,

but a sufficient amount reaches Sacramento to cause a decided rise on the gage at that point.

Rio Vista is 26 miles from the mouth of the river and 38 miles below Sacramento City. The drainage area above the station is 30,047 square miles. The station is about 3 miles below the mouth of Steamboat Slough through which the drainage of the Coast Range and the accumulated waters of Yolo Basin are discharged into the Sacramento River.

TRIBUTARIES OF THE SACRAMENTO.

It would be practically impossible to enumerate all the small water-courses that feed the Sacramento River during periods of heavy rainfall, or even the streams that are kept alive during the rainy season, and no attempt will be made in this paper to name or describe any stream other than those that materially affect the water levels of the main river. The main and tributary streams of both valleys are shown in figure No. 1, frontispiece.

The most important tributaries of the Sacramento flow westward from the Sierra Nevada, the largest of which, named from north to south, are the Pit, Feather, and American Rivers. There are several creeks that run the greater part of the year, chief of which are Battle, Antelope, Mill, Deer, Chico, and Butte. While all of these creeks have heavy discharges in times of heavy rainfall it has not yet been practicable to establish permanent stations on any of them. They are, however, considered in times of floods.

The Pit River rises in the Warner Mountains at an elevation of some 10,000 feet and flows southwestward to its junction with the Sacramento about 3 miles north of Kennett. This river is really the northeastern extension of the Sacramento and some geographers consider the Pit and Sacramento as one stream. The total fall of the Pit is about 6,000 feet. From the mouth of Falls River, at Falls City, to where it joins the Sacramento, a distance of about 87 miles, the Pit is deeply intrenched in rocky canyons. The principal tributaries of the Pit are the McCloud and Falls Rivers, although Montgomery, Hatchet, Hat, Squaw, and Burney Creeks add greatly to its discharge during periods of heavy rainfall. In times of heavy flow the most of the creeks named practically leap into the Pit as roaring cataracts. There is no Weather Bureau gauging station on the Pit River, but, as has been stated, the combined output of the Pit and the upper Sacramento River is measured on the Kennett gauge where a rise of from 15 to 20 feet often occurs in 24 hours.

The precipitation of the Pit River drainage becomes somewhat less as the northeastern end of its watershed is approached, especially in the level portions of Modoc County. It increases in the higher levels

of the Warner Mountains, and varies from 20 to 30 inches annually. Some snow falls along the western slopes of the Warner Mountains and occasionally in the plains adjacent to Alturas. Within a radius of 20 to 40 miles adjacent to Kennett, in the lower Pit and upper Sacramento watersheds, the annual precipitation sometimes exceeds 100 inches. In 1909 the rainfall at Kennett for the three months ending with March was 86.42 inches, of which 54.08 inches fell in January and 24.30 in February. The annual precipitation at Kennett for 1909 was 115.92 inches.

The Feather River drains an extensive area south of the Honey Lake drainage basin and empties into the Sacramento at Vernon, 20 miles above Sacramento City. The drainage area above its mouth is something over 7,000 square miles. Its principal tributaries are the Yuba, which joins it near Marysville, and the Bear, which empties into it 17 miles below Marysville and 1 mile above Nicolaus. The output of the Feather River will probably exceed that of any of the tributaries of the Sacramento and is one of the principal streams to be reckoned with in times of flood. It rises on Mount Lassen at an elevation of nearly 10,000 feet and flows southward, being joined in the high Sierra by numerous forks, the chief of which are the North, Middle, and South Forks. The Feather-Yuba drainage includes the western slopes of the Sierra Nevada lying between the Pit and American Basins. The mean annual precipitation in the Feather-Yuba drainage area varies from 20 inches in the valley to 60 or 70 inches in the higher regions; occasionally as much as 100 inches falls. In the higher regions it is mostly in the form of snow, which often remains on the ground until June and sometimes July. On the summit of Mount Lassen the snow rarely ever disappears. From Oroville to its mouth the Feather flows practically parallel with the Sacramento, and during all floods of which there is a record it has overflowed its west bank at a point near Hamilton Bend and discharged its surplus water into a basin lying north of Marysville Buttes, thence into the Sacramento through Butte Slough. This water in 1909 was the deciding factor in the breaking of the levees at Moons Bend on the Sacramento River below Colusa and the flooding of Colusa Basin.

Upon the completion of an enormous dam by the Great Western Power Co. in the lower portion of Big Meadows Valley, that part of the North Fork of the Feather which drains this valley will be changed into a large reservoir that will occupy an area of about 40 square miles. The dam, which will impound about 1,250,000 acre-feet of water, will be 110 feet above the ordinary water level of the valley. As the North Fork of the Feather, besides bearing the drainage of Mount Lassen, is the most extensive watershed of any of the branches of this river, it will be seen that this huge reservoir will exercise a modifying effect on future flood conditions in the main stream. A

regular river and rainfall station is maintained at Oroville on the Feather, 32 miles above its confluence with the Yuba and 50 miles from the mouth of the river. The drainage area above the station is 3,100 square miles. The fall between Oroville and the mouth of the Feather is about 2.6 feet per mile. Another regular river and rainfall station has recently been established on the Feather at Nicolaus, 16 miles below the mouth of the Yuba, 1 mile below the mouth of the Bear, and 10 miles above the mouth of the Feather.

The Yuba River rises at an elevation of about 8,000 feet and flows southwestward to its junction with the Feather near Marysville. It is fed by three forks, the North, Middle, and South, which drain the snow fields of the high mountains. A regular river and rainfall station has been maintained for many years at Marysville, which is 26 miles above the mouth of the river. The drainage area above Marysville is 3,540 square miles. In times of flood or heavy rainfall special telegraphic reports are received from Downieville, on the North Fork of the Yuba, about 95 miles above Marysville.

The Bear River drains a small area, not over 300 square miles, between the Yuba and American watersheds. It rises at an elevation of about 5,500 feet and flows southwestward to its junction with the Feather. This stream rises rapidly under the influence of heavy rains or melting snows in the higher regions of its watershed. With the cessation of rain the river quickly subsides and reaches its normal stage in a few hours' time. A special river station has been established on the Bear near Colfax, from which telegraphic reports are received in times of heavy rainfall.

The American River drains that part of the western slopes of the Sierra Nevada lying between the Bear and Yuba on the north and the Cosumnes and Mokelumne on the south. It flows southwestward and joins the Sacramento at the city of Sacramento. The drainage area above its mouth is about 2,000 square miles and its total fall is about 9,000 feet. Like the Feather and Yuba Rivers, the American branches out into numerous forks, all of which tap the snow fields of the high mountain ranges. In the higher part of its basin are numerous small lakes. There are two stations on this stream: One at Folsom, 25 miles above Sacramento, from which reports of river and rainfall are received the year round, and another on the Middle Fork, near East Auburn, from which reports are telegraphed in times of high water or heavy rainfall. It has been estimated that when a stage of 10 feet is reached on the Middle Fork gauge, assuming that all other forks are proportionally high, the main river at Folsom will be augmented by 10 or 11 feet when the gauge at the last-named point is at or near a 10-foot stage. The advance flood wave, starting at Folsom with a 20-foot head, will reach Sacramento city in about six hours. With a 25-foot head at Folsom the swell will be felt at

Sacramento in about five hours. The rate of progress of this stream becomes rapidly less as the water subsides, and at extreme low water the river becomes very sluggish, especially in the vicinity of Sacramento. Between Fair Oaks and Folsom the river is mostly confined within high banks. The American rarely retains a full head of water longer than a few hours after the cessation of rain, and for this reason its flood waves usually pass into the Sacramento before the output of the Feather-Yuba reaches its mouth. However, with a protracted spell of heavy rainfall that is coextensive with the watersheds of the American, Feather, and Yuba Rivers, the American remains at flood stage until the approach of the Feather River output, or such a part thereof as does not escape into the basins on each side of the Sacramento above the mouth of the American. The mean annual precipitation of the American watershed varies from 20 inches in the vicinity of Sacramento to 25 or 30 inches in the foothills. In the higher regions it amounts to 60 or 70 inches, and much of it is in the form of snow. Melting snows in the higher regions affect the American during the first warm days of spring, but this of itself rarely raises the river more than a few feet, and this usually flattens out before reaching Sacramento. The most potent factor in producing floods in the American is the combined influence of heavy rainfall and melting snows in its upper watershed.

Of the western tributaries of the Sacramento or those that flow from the Coast Range, the most important are Stony, Cache, Putah, and Cottonwood Creeks. In addition to these are Clear and Thomas Creeks, streams of small discharges and restricted watersheds.

Cottonwood Creek empties into the Sacramento near the town of Cottonwood. Its numerous small forks rise in the Coast Range at elevations ranging from 4,000 to over 6,000 feet. Although the main stream is east of the Coast Range proper, the total area drained by this creek is something over 900 square miles. The mean annual precipitation ranges from 20 to 25 inches in that part contiguous to the Sacramento River to 50 inches or more in the higher regions, where much of it is in the form of snow. This stream has a heavy discharge during periods of excessive rainfall, but it has not yet been practicable to establish a Weather Bureau river gauge in its watershed.

Stony Creek rises west of the Sacramento River at an elevation of about 5,000 feet and flows northward between the Coast Range proper and the foothills until it breaks through the hills and turns eastward through the plains toward the Sacramento, into which it discharges at a point near Monroeville. Stony Creek is the last southerly watercourse that discharges directly into the Sacramento River. The mean annual precipitation in the watershed of Stony Creek varies from 25 inches in the valley to about 40 inches in its

most elevated feeders. Some snow falls in the higher regions, but this form of precipitation is rarely a factor in the flood situation.

The Weather Bureau maintains a regular river and rainfall station at St. John, about 3 miles above the point where the creek joins the Sacramento River, and a special rainfall station is in operation at Stonyford, about 45 miles above St. John, from which heavy rainfall is reported by telegraph. During the summer months the creek in the vicinity of St. John is practically dry, but during the winter months, especially during periods of heavy rainfall it rises rapidly, sometimes carrying away bridges, as was the case during the floods of 1907 and 1909. Stages over 6 feet in the lower reaches of the creek exercise a marked influence on the run-off of the Sacramento between its junction with the Sacramento and Colusa. Records show that stages between 9 and 12 feet on the St. John gauge will raise the river in the vicinity of Colusa from 5 to 7 feet when the Colusa gauge is at or near a 15-foot stage. The distance from the mouth of Stony to Colusa is about 50 miles and the first effect of the Stony flood wave is felt in between 14 and 16 hours, according to the intensity of the wave. The average fall per mile between the mouth of the creek and Colusa is about 2.3 feet. The creek falls rapidly after the cessation of rain and rarely maintains a stage as high as 8 feet for more than a few hours. At 12 feet the creek overflows its banks in the vicinity of St. John.

The United States Reclamation Service has recently completed a large reservoir in the vicinity of Orland, where a sufficient amount of water has been impounded from Stony Creek to irrigate some 14,000 acres.

Cache Creek drains that part of the eastern slope of the Coast Range lying between Stony and Putah Creeks. It rises in Clear Lake and flows southward through Yolo Basin and reaches the Sacramento River through Cache and Steamboat Sloughs a short distance above Rio Vista. Clear Lake has a drainage basin of about 450 square miles.

Putah Creek drainage basin lies between Cache Creek and Napa Valley. It rises in the St. Helena Range and flows southward through Yolo Basin, thence through Cache and Steamboat Sloughs into the Sacramento River.

The mean annual precipitation in the Cache and Putah Creek Basins varies from about 20 inches in Yolo Basin to 50 or 60 inches in the higher regions. Some snow falls in the upper forks of Putah and in the feeders of Clear Lake, although there is no appreciable increase in the run-off of either stream from this form of precipitation.

Both Cache and Putah Creeks have a heavy discharge during periods of heavy rainfall, and their flood waters intensify conditions from Rio Vista to Collinsville and throughout the island districts in

the lower Sacramento and San Joaquin Rivers. All water that reaches Yolo Basin, whether from the hills or from the overflow of Colusa Basin, or through weirs and other openings along the west side of the Sacramento River, is borne back into the Sacramento River through the outlets that carry the combined discharge of Cache and Putah Creeks. During the floods of 1907 and 1909 the discharge of the accumulated water of Yolo Basin into the Sacramento River was sufficient to reverse the current of this stream for several miles above the mouth of Steamboat Slough, especially during flood tide.

No Weather Bureau gauges have been established on Cache or Putah Creeks, but arrangements are being made whereby gauge readings may be secured from several points in Yolo Basin during flood periods.

THE SAN JOAQUIN DRAINAGE BASIN.

The San Joaquin Valley is bounded on the east by the Sierra Nevada, on the south by the Tehachapi Cross Range, on the west by the Coast Range; on the south it merges into the Sacramento Valley in the region of the Mokelumne and Cosumnes Rivers.

The San Joaquin River, the trunk stream of the southern end of the Great Valley, and of the San Joaquin Valley, rises in the elevated regions of the Southern Sierras at a point south of the Yosemite National Park and flows southward to the floor of the valley, thence northwestward to Suisun Bay. Its total length is quoted as 350 miles. The river has been popularly divided into two sections, the upper and lower. The logical point between the divisions is a few miles above Mendota, where the river bends abruptly from a southwesterly to a northwesterly course.

Precipitation in the valley itself, or along the course of the river, ranges from something over 16 inches annually in the vicinity of Stockton to less than 5 inches in the region of Bakersfield. It increases rapidly as the Sierra Nevada are approached. The main water supply, however, of this stream is drawn from melting snows from the high mountain peaks of the Southern Sierra, many of which are almost always covered with snow. For this reason the mean maximum flow generally occurs in May and June, sometimes in July.

Three river and rainfall stations, having uninterrupted records of six years, are maintained on the San Joaquin River proper. Named from south to north they are Friant, Firebaugh, and San Joaquin Bridge.

Tables of highest, lowest, and mean stages for each month and the mean for each year follow.

The tabular values are also presented graphically in figures 16 to 22b, inclusive.

Mean monthly river stages, San Joaquin system.

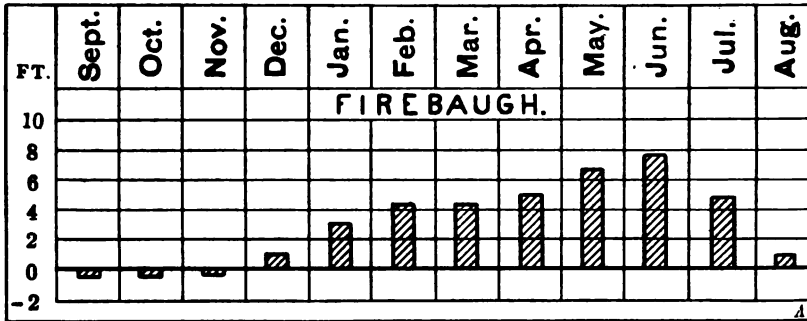


FIG. 16.—Mean monthly river stages.

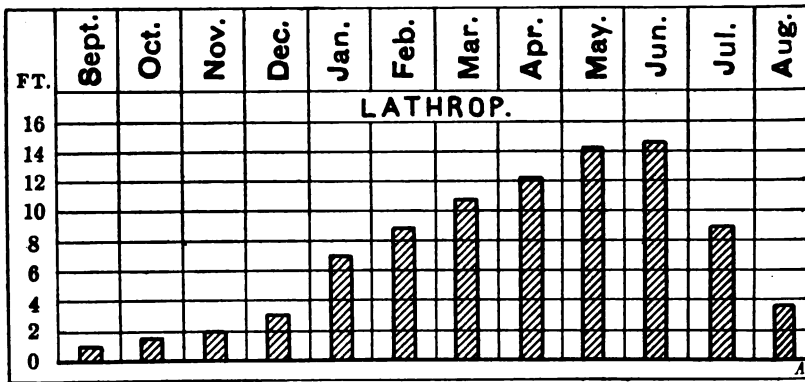


FIG. 16a.—Mean monthly river stages.

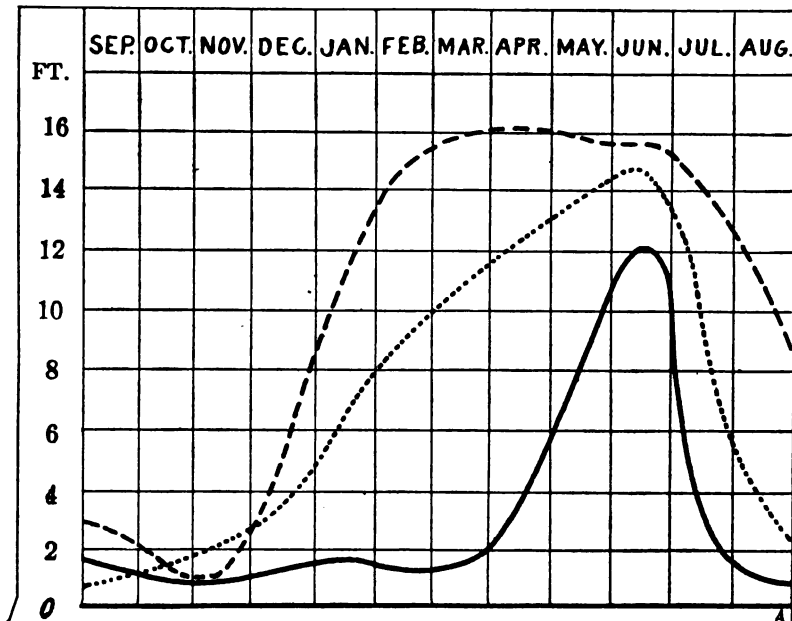


FIG. 17.—Me
high; solid li:

er stages, Lathrop, Cal. Broken line, season 1906-7, unusually
lly low; dotted line, mean stages for a 12-year period.

*Highest, lowest, and mean seasonal stages, San Joaquin system.
(In feet.)*

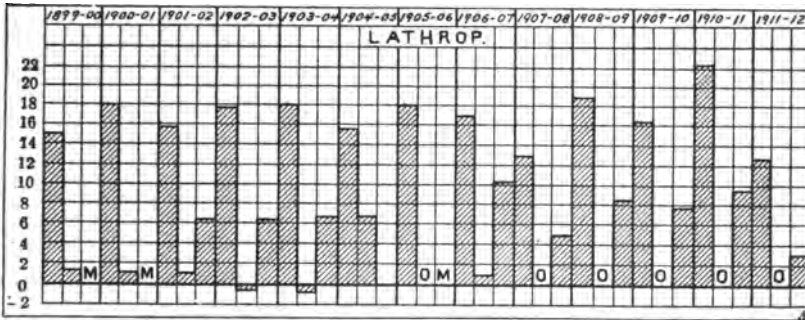


FIG. 18.—Highest, lowest, and mean stages.

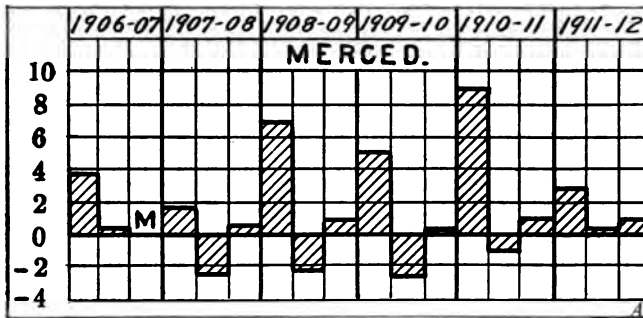


FIG. 19.—Highest, lowest, and mean stages.

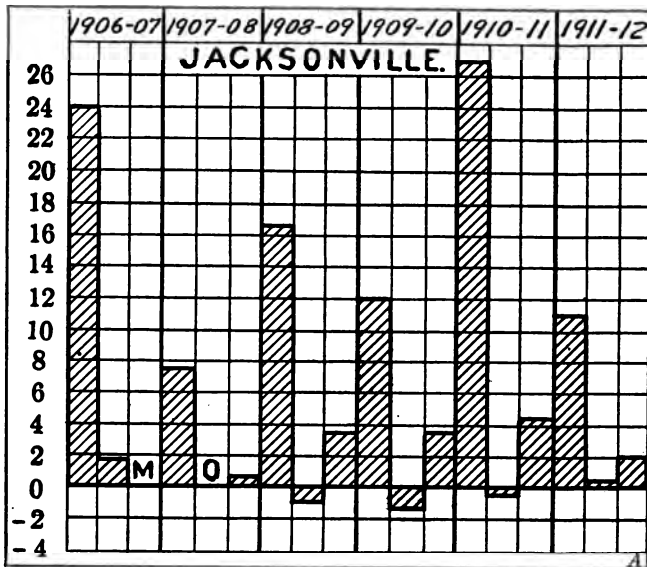


FIG. 20.—Highest, lowest, and mean stages.

Highest, lowest, and mean seasonal stages, San Joaquin system—Continued.

(In feet.)

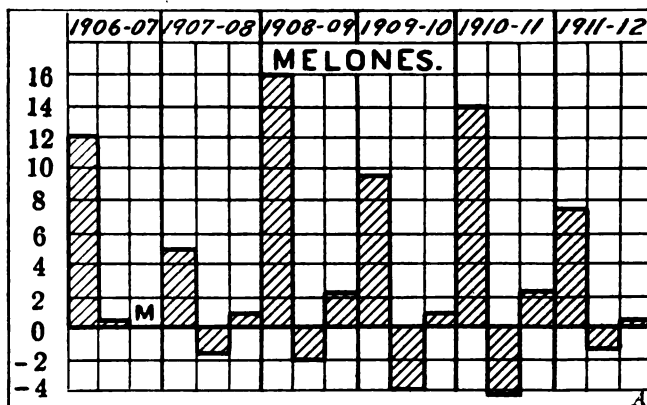


FIG. 20a.—Highest, lowest, and mean stages.

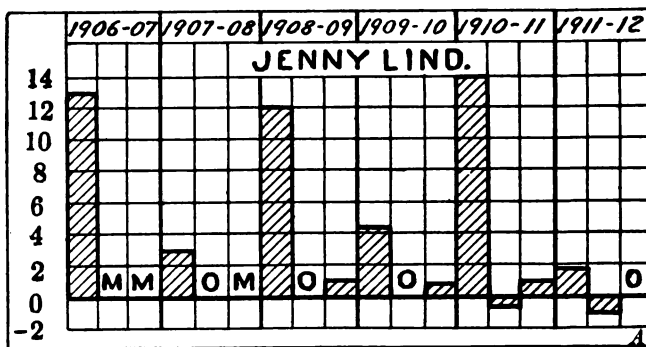


FIG. 20b.—Highest, lowest, and mean stages.

Highest, lowest, and mean seasonal stages, San Joaquin system—Continued.

(In feet.)

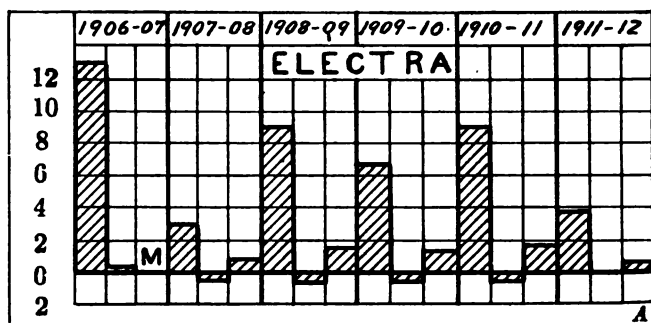


FIG. 21.—Highest, lowest, and mean stages.

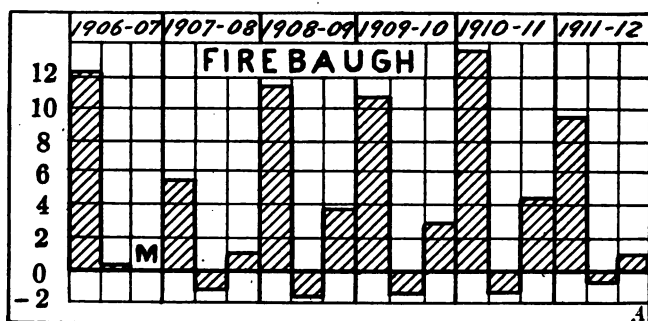


FIG. 22.—Highest, lowest, and mean stages.

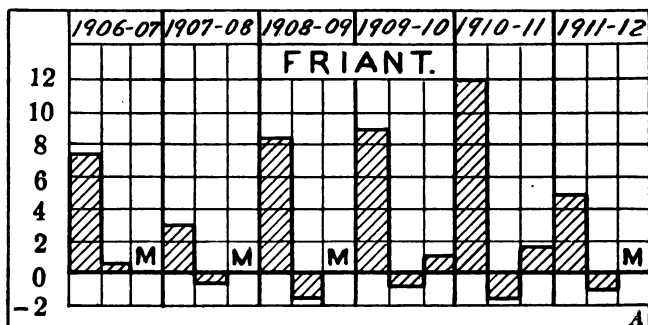


FIG. 22b.—Highest, lowest, and mean stages.

Highly detailed and professional

Figure 10: The left hand plot shows the χ^2 distribution of the α parameter for the α parameter of the α parameter. The right hand plot shows the χ^2 distribution of the α parameter for the α parameter.

[illegible]

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1999	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2000	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2001	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2002	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2003	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2004	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2005	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2006	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2007	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2008	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2009	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2010	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2011	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2012	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2013	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2014	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		
2015	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25																																																																													

TABLE NO. 2.—*Highest, lowest, and mean stages for each month and the mean for each year at Firebaugh.*

Stages in bold-face type indicate the extremes for each year.
 Firebaugh is on the San Joaquin River, 160 miles from its mouth and 111 miles above Lathrop. Elevation, 153.5 feet; flood stage, 12 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1900-7.....																		
1907-8.....	1.1	-0.4	0.4	0.6	-0.5	0.4	1.8	0.2	0.4	2.3	0.2	1.2	8.2	3.4	4.3	6.7	4.6	5.5
1908-9.....	-1.1	-1.4	-1.3	-0.5	-1.4	-1.1	-1.3	-1.5	-1.4	-4	-1.3	-0.9	2.9	1.4	1.7	2.6	1.2	1.8
1909-10.....	-5	-1.1	-0.9	-0.8	-1.2	-1.0	3.4	-1.2	-1.4	9.2	2.3	4.2	10.2	-5	4.2	10.1	4.4	6.4
1910-11.....	2.0	-1.2	-0.8	-0.8	-1.0	-0.9	1.0	-0.8	-0.9	8.8	1.0	0.5	8.9	-8	1.5	5.0	2.5	3.6
1911-12.....	1.0	0.3	0.7	1.6	0.4	0.8	1.0	0.4	0.7	0.6	0.3	0.4	8.8	0.3	0.4	12.5	3.5	7.4
1906-12.....	2.0	-1.4	-0.4	1.6	-1.4	-0.4	3.4	-1.5	-0.2	9.2	-1.3	0.9	11.0	-0.8	3.1	12.5	-0.7	4.1

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	11.5	4.7	8.1	11.4	8.1	10.1	11.5	9.8	10.9	12.5	10.5	11.5	11.8	7.2	10.3	6.6	0.5	3.4	.....
1907-8.....	3.9	1.0	2.5	5.2	3.3	2.2	5.5	1.4	3.0	4.3	1.3	2.4	1.5	-0.7	4	0.8	-1.3	-0.5	1.3
1908-9.....	5.4	3.2	4.2	8.4	3.1	5.7	10.6	8.1	9.5	12.5	9.2	11.7	11.6	2.2	8.0	2.1	-0.6	0.2	3.8
1909-10.....	4.9	2.4	3.7	8.4	2.8	5.7	8.4	5.6	7.4	8.7	2.0	4.8	2.1	-1.1	0.2	-1.0	-1.2	-1.1	2.8
1910-11.....	11.0	3.4	7.6	9.3	5.7	7.7	10.1	6.9	8.4	13.6	9.2	11.9	12.6	6.3	10.6	5.2	1.0	2.4	4.5
1911-12.....	0.5	-0.7	-0.5	-0.8	-0.7	-0.4	6.7	-0.7	2.6	9.6	1.7	5.9	1.7	-0.1	0.5	-0.2	-0.4	-0.2	0.9
1906-12.....	11.5	-0.7	4.3	11.4	-0.7	5.2	11.5	-0.7	7.0	13.6	1.3	8.0	12.6	-1.1	5.0	6.6	-1.3	0.7	2.7

TABLE No. 3.—Highest, lowest, and mean stages for each month and the mean for each year at Lathrop.

Stages in bold-face type indicate the extremes for each year.

Lathrop is on the San Joaquin River, 48 miles from its mouth. Elevation, 1.9 feet; flood stage, 17 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1899-1900.																		
1900-1901.																		
1901-2.	1.5	1.1	1.4	6.5	1.1	3.8	14.0	2.0	5.9	10.0	3.2	5.5	14.7	6.8	9.8	6.4	4.7	5.5
1902-3.	3.3	1.4	2.1	3.5	1.1	2.3	3.9	2.8	3.3	6.5	1.8	3.0	3.7	4.5	2.2	11.6	8.5	15.7
1903-4.	1.0	1.1	1.6	6	1.3	1.2	3.5	2.2	1.8	5.5	1.8	3.0	15.3	1.7	2.8	12.4	2.0	4.4
1904-5.	4.2	2.2	3.2	13.2	4.6	8.3	5.7	2.7	2.0	2.1	2.1	1.4	1.5	3.0	1.7	16.1	5.3	7.8
1905-6.	4.2	2.2	3.2	13.2	4.6	8.3	5.7	2.7	2.0	2.1	2.1	1.4	1.5	3.0	1.7	16.1	5.3	7.8
1906-7.	5.6	1.8	3.3	2.0	1.3	1.3	1.9	1.0	1.4	12.8	1.1	5.2	16.3	8.8	4.0	12.8	3.9	7.3
1907-8.	3.9	2.0	2.9	2.6	1.4	1.8	2.5	1.4	2.0	4.8	1.5	2.6	18.7	7.1	4.0	16.7	12.4	14.4
1908-9.	2.0	1.0	1.4	1.2	1.0	1.3	7.7	0	3.4	1.2	3.3	9.8	15.5	7.3	13.4	15.2	15.0	16.4
1909-10.	2.0	1.0	1.4	1.2	1.0	1.3	7.7	0	3.4	1.2	3.3	9.8	15.5	7.3	13.4	15.2	15.0	16.4
1910-11.	2.8	1.0	1.7	1.7	1.0	1.3	8.8	0	3.4	3.3	1.2	1.4	15.1	1.4	1.8	22.5	10.9	15.4
1911-12.	2.5	1.0	1.6	1.6	1.0	1.3	1.5	1.2	1.3	1.6	1.2	1.4	15.1	1.4	1.8	22.5	10.9	15.4
1899-1912.	5.6	1.2	1.3	13.2	1.5	1.6	14.0	0	2.1	14.0	0	3.1	18.7	4	6.8	22.5	6	9.0

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1899-1900.																			
1900-1901.																			
1901-2.	10.0	5.1	8.3	10.7	7.4	9.0	9.2	13.3	15.2	11.0	13.9	10.6	2.0	5.4	2.0	1.3	1.7	1.7	.....
1902-3.	16.5	12.1	14.4	14.8	9.6	12.1	17.6	16.1	17.3	13.7	16.5	16.5	2.0	14.4	11.2	3.4	7.2	6.5	.....
1903-4.	13.2	6.2	9.8	14.4	7.3	11.8	15.7	11.8	15.8	13.3	14.9	13.2	2.9	6.8	2.9	2.9	1.6	1.6	6.5
1904-5.	16.4	10.0	13.3	16.0	10.9	14.3	18.0	12.5	16.1	13.2	14.6	12.9	2.1	6.4	1.9	1.0	2.6	6.9	.....
1905-6.	14.7	6.8	10.1	12.8	9.8	10.6	16.4	10.8	15.2	12.6	14.2	12.4	2.0	6.2	2.0	2.0	2.6	6.9	.....
1906-7.	19.2	13.0	16.0	17.4	15.1	15.8	17.5	16.7	17.0	16.7	17.3	17.9	15.9	17.0	15.7	6.0	12.4	10.4	.....
1907-8.	8.9	5.0	7.2	11.6	4.8	8.0	12.9	7.3	10.0	4.6	7.9	4.5	1.2	2.8	1.0	4.0	9.1	4.7	.....
1908-9.	14.7	9.8	12.2	16.7	10.6	13.2	17.2	15.3	16.3	15.6	16.9	16.4	6.8	13.2	6.3	1.5	3.0	8.6	.....
1909-10.	14.9	8.0	11.6	16.5	12.1	14.0	16.6	14.0	15.3	16.8	16.4	16.4	6.8	13.2	6.3	1.5	3.0	8.6	.....
1910-11.	19.3	9.6	15.8	16.7	14.5	15.7	17.0	14.7	15.8	16.4	17.3	17.7	14.2	16.1	13.8	2.3	7.0	9.4	.....
1911-12.	2.8	1.6	2.2	14.7	1.0	2.4	12.6	2.2	7.7	5.9	12.3	5.4	1.0	10.1	1.6	2.3	7.0	9.4	.....
1899-1912.	19.3	6	10.7	17.9	1.0	12.1	18.0	2.2	14.3	4.3	14.6	17.9	8	9.0	15.7	0	3.8	7.1	.....

TABLE NO. 4.—*Highest, lowest, and mean stages for each month and the mean for each year at Merced Falls.*

Stages in bold-face type indicate the extremes for each year.
 Merced Falls is on the Merced River, 35 miles from its mouth. Elevation about 321.1 feet. There is no danger from floods.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	0.4	0.0	0.2	0.8	0.0	0.1	0.2	0.0	0.0	0.7	0.0	0.3	4.0	0.5	1.0	2.1	0.8	1.2
1907-8.....	0.0	-2.0	-0.8	0.3	-2.0	-1.0	0.0	-2.0	-1.0	0.0	-2.0	0.0	1.1	0.4	0.5	0.8	0.3	0.4
1908-9.....	0.2	-2.6	-1.0	0.0	-2.0	-0.7	1.3	-1.0	-0.2	4.8	0.4	0.8	7.1	-0.9	1.5	1.5	1.0	1.7
1909-10.....	0.7	-1.0	-0.8	0.0	-1.0	-0.4	0.2	-1.0	-0.5	0.8	-1.0	0.3	5.3	-1.0	1.3	1.0	0.7	0.8
1910-11.....	0.5	0.4	0.3	0.3	-0.3	-0.3	0.4	0.3	0.3	0.3	0.2	0.2	9.0	-1.2	1.1	4.1	1.0	1.6
1911-12.....	0.7	-2.6	-0.4	0.8	-2.0	-0.3	1.3	-2.0	-0.2	4.8	-2.0	0.0	9.0	-1.0	1.0	4.9	0.3	1.0
1906-12.....	6.0	0.9	2.5	2.9	1.7	2.4	3.5	2.1	2.7	3.8	1.6	2.7	2.8	1.0	1.7	1.2	0.4	0.7
1907-8.....	1.1	0.6	0.8	2.0	1.6	1.2	1.9	1.0	1.3	1.2	0.7	1.0	1.7	0.3	0.5	0.5	-2.4	-0.4
1908-9.....	1.4	0.9	1.0	2.4	1.0	1.6	3.1	2.0	2.5	3.9	1.8	2.7	1.8	0.5	1.0	0.5	0.0	0.3
1909-10.....	2.1	0.8	1.3	2.8	1.3	2.0	2.4	1.5	2.0	1.8	0.5	1.0	1.0	0.4	0.4	0.0	-1.0	0.3
1910-11.....	5.2	1.4	2.5	2.8	1.7	2.1	3.5	2.0	2.5	4.0	2.4	3.3	3.0	1.0	1.9	1.0	0.5	0.7
1911-12.....	1.5	0.3	0.8	1.5	0.6	0.9	2.8	0.9	1.6	3.1	0.8	1.7	0.7	0.3	0.5	0.3	0.2	0.3
1906-12.....	6.0	0.3	1.5	2.9	0.6	1.7	3.5	0.9	2.1	4.0	0.5	2.1	3.0	0.0	1.0	1.2	-2.4	0.1

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	6.0	0.9	2.5	2.9	1.7	2.4	3.5	2.1	2.7	3.8	1.6	2.7	2.8	1.0	1.7	1.2	0.4	0.7	0.5
1907-8.....	1.1	0.6	0.8	2.0	1.6	1.2	1.9	1.0	1.3	1.2	0.7	1.0	1.7	0.3	0.5	0.5	-2.4	-0.4	0.5
1908-9.....	1.4	0.9	1.0	2.4	1.0	1.6	3.1	2.0	2.5	3.9	1.8	2.7	1.8	0.5	1.0	0.5	0.0	0.3	0.7
1909-10.....	2.1	0.8	1.3	2.8	1.3	2.0	2.4	1.5	2.0	1.8	0.5	1.0	1.0	0.4	0.4	0.0	-1.0	0.3	0.7
1910-11.....	5.2	1.4	2.5	2.8	1.7	2.1	3.5	2.0	2.5	4.0	2.4	3.3	3.0	1.0	1.9	1.0	0.5	0.7	1.1
1911-12.....	1.5	0.3	0.8	1.5	0.6	0.9	2.8	0.9	1.6	3.1	0.8	1.7	0.7	0.3	0.5	0.3	0.2	0.3	0.6
1906-12.....	6.0	0.3	1.5	2.9	0.6	1.7	3.5	0.9	2.1	4.0	0.5	2.1	3.0	0.0	1.0	1.2	-2.4	0.1	0.6

TABLE NO. 5.—*Highest, lowest, and mean stages for each month and the mean for each year at Jacksonville.*

Stages in bold-face type indicate the extremes for each year.
 Jacksonville is on the Tuolumne River, 64 miles from its mouth. Elevation, 601.7 feet; flood stage, 20 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	2.1	0.0	0.9	1.8	0.6	0.9	1.4	0.5	0.8	3.6	0.4	1.7	8.6	1.6	2.4	6.6	3.0	4.3
1907-8.....	.4	.2	.3	3.6	.0	.0	1.0	.3	.4	1.5	.5	.7	3.2	1.8	2.4	3.8	2.0	2.4
1908-9.....	.5	.0	.5	3.6	1.0	1.0	9.0	1.0	3.1	12.0	2.0	3.9	17.0	5.5	5.7	9.4	3.6	5.0
1909-10.....	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	1.3	.0	.6	3.2	.2	1.0	8.0	3.0	4.2	4.6	2.4	3.1
1910-11.....	3.4	-1.2	.4	1.0	.2	.2	1.3	.2	.3	3.3	.2	.2	27.0	.2	4.4	12.0	2.8	4.7
1911-12.....	1.4	.2	.5	.2	.2	.2	1.0	.2	.3	.3	.2	.2	1.8	.3	.6	.8	.4	.6
1906-12.....	3.4	-1.1	.3	3.6	-1.1	.5	9.0	.0	1.0	12.0	.2	1.5	27.0	.2	3.3	12.0	.4	3.4

Year.	March.			April.			May.			June.			July.			August.			An nual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	24.0	2.8	6.8	8.2	4.6	6.5	10.2	6.2	7.7	12.0	5.6	8.6	10.2	5.0	7.5	5.2	2.2	3.3	.....
1907-8.....	5.0	2.8	3.7	7.6	2.8	5.1	7.6	4.2	5.8	6.4	3.2	4.8	3.2	1.4	2.1	2.0	.4	.9	2.6
1908-9.....	5.6	3.4	4.0	7.6	3.6	5.9	9.0	6.1	7.8	11.9	6.9	9.2	8.0	2.1	4.4	2.0	.6	.5	3.7
1909-10.....	8.2	4.2	5.4	9.0	5.6	7.2	8.5	5.5	7.5	8.6	2.8	4.7	2.6	.6	1.4	.6	1.1	.3	3.4
1910-11.....	12.0	4.0	6.8	8.6	5.4	7.2	10.4	6.2	7.9	13.0	7.6	10.8	10.0	4.2	7.6	4.0	1.1	2.3	4.5
1911-12.....	3.6	.4	2.0	5.4	2.4	3.2	9.8	4.4	6.7	11.0	3.6	6.9	3.0	1.0	2.4	.8	.1	.5	2.0
1906-1912.....	24.0	.4	4.8	9.0	2.4	5.8	10.4	4.2	7.2	13.0	2.8	7.5	10.2	.6	4.2	5.2	-.6	1.3	5.2

TABLE NO. 6.—*Highest, lowest, and mean stages for each month and the mean for each year at Melones.*

Stages in bold-face type indicate the extremes for each year.
Melones is on the Stanislaus River, 64 miles from its mouth. No danger from floods.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7																		
1907-8	0.2	-0.2	0.0	-0.2	-0.3	-0.3	-0.1	-0.6	-0.3	1.1	-0.6	0.4	5.2	1.0	1.7	6.0	3.4	4.3
1908-9	-1.2	-1.8	-1.7	-1.4	-1.9	-1.6	-1.0	-1.9	-1.6	0.2	-1.4	-2.8	0.7	-0.9	3.8	7.0	2.5	-3.7
1909-10	-1.9	-3.6	-3.2	-2.7	-4.0	-3.3	0.5	1.9	0.5	9.4	0.5	2.8	6.0	0.3	2.4	3.0	1.8	2.4
1910-11	-3.4	-4.1	-4.0	-3.9	-4.0	-4.0	-1.5	-3.9	-3.2	0.5	-0.7	-1.2	14.0	-1.0	2.4	8.0	1.8	3.1
1911-12	1.0	0.9	0.9	0.9	0.7	0.8	0.5	-1.1	0.0	0.0	-0.3	-1.1	1.2	-0.2	0.0	0.7	-0.5	0.4
1906-1912	1.0	-4.1	-1.6	0.9	-4.0	-1.3	9.5	-3.9	-0.6	9.4	-1.4	0.6	16.0	-1.0	1.7	8.0	-0.9	2.2

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7	12.2	3.2	6.0	5.6	3.2	4.5	6.2	4.5	5.1	7.0	5.2	6.2	2.0	2.0	4.0	0.1	1.2	1.2	0.7
1907-8	2.3	-2.7	1.2	4.9	1.0	2.9	4.0	2.3	2.9	2.8	2.9	2.4	2.2	-0.9	2.7	-1.2	-0.8	2.2	0.7
1908-9	4.0	2.3	3.0	9.0	3.0	5.0	8.1	4.5	6.8	5.5	4.9	6.4	4.5	1.0	2.0	1.0	1.6	1.6	2.2
1909-10	8.0	3.5	5.1	7.8	4.0	6.1	6.5	4.2	5.1	5.2	5.2	2.3	2.3	-2.0	-3.0	-4.0	-3.8	2.7	0.7
1910-11	8.0	1.8	5.0	9.0	4.5	6.4	10.0	5.0	7.0	10.9	5.5	8.7	6.0	1.8	3.2	1.7	1.0	1.2	2.2
1911-12	1.3	0.0	0.7	2.5	0.8	1.3	6.5	1.5	4.2	7.3	1.0	3.7	1.0	-1.1	0.4	-1.1	-0.6	1.1	0.7
1906-1912	12.2	-0.7	3.5	9.0	0.8	4.5	10.0	1.5	5.2	10.9	0.2	5.0	6.8	-2.0	1.4	2.0	-4.0	-0.6	1.2

TABLE NO. 8.—*Highest, lowest, and mean stages for each month and the mean for each year at Electra.*

Stages in bold-face type indicate the extremes for each year.
Electra is on the Mokelumne River 70 miles from its mouth and 55 miles above its junction with the Cosumnes River. Elevation, 669.8 feet; flood stage, 12 feet.

Year.	September.			October.			November.			December.			January.			February.		
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
1906-7.....	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	1.7	0.1	0.3	4.0	1.5	1.9	4.8	2.5	2.9
1907-8.....	0.2	0.1	0.1	1.0	0.2	0.1	0.1	0.1	0.1	1.7	0.1	0.3	1.5	0.4	1.7	3.9	1.6	2.6
1908-9.....	0.2	0.1	0.1	1.0	0.2	0.1	0.1	0.1	0.1	1.7	0.1	0.3	1.5	0.4	1.7	3.9	1.6	2.6
1909-10.....	0.2	0.1	0.1	1.0	0.2	0.1	0.1	0.1	0.1	1.7	0.1	0.3	1.5	0.4	1.7	3.9	1.6	2.6
1910-11.....	0.2	0.1	0.1	1.0	0.2	0.1	0.1	0.1	0.1	1.7	0.1	0.3	1.5	0.4	1.7	3.9	1.6	2.6
1911-12.....	0.2	0.1	0.1	1.0	0.2	0.1	0.1	0.1	0.1	1.7	0.1	0.3	1.5	0.4	1.7	3.9	1.6	2.6
1906-1912.....	0.2	0.1	0.1	1.0	0.2	0.1	0.1	0.1	0.1	1.7	0.1	0.3	1.5	0.4	1.7	3.9	1.6	2.6

Year.	March.			April.			May.			June.			July.			August.			Annual.
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.	
1906-7.....	13.0	2.2	4.0	3.6	2.6	3.1	3.8	2.4	3.1	4.6	2.4	3.4	3.8	1.6	2.6	1.5	0.1	0.7	0.7
1907-8.....	1.2	1.7	1.0	2.8	2.9	1.9	2.4	1.2	1.8	2.4	2.4	1.6	3.7	1.5	2.5	0.5	0.1	0.1	0.7
1908-9.....	2.6	1.8	2.4	3.5	2.2	2.5	4.0	3.2	3.6	4.6	3.0	3.9	3.0	1.1	1.9	0.1	0.1	0.1	1.5
1909-10.....	4.0	1.4	2.6	3.8	2.2	3.0	3.6	2.8	3.2	3.1	3.9	1.7	3.9	0.0	0.3	0.1	0.1	0.1	1.4
1910-11.....	4.3	1.4	2.7	4.6	2.4	3.2	4.5	2.5	3.3	5.1	3.0	4.3	3.2	0.7	2.1	0.6	0.1	0.1	1.7
1911-12.....	1.3	0.2	0.6	1.6	0.6	0.9	3.7	1.5	2.5	3.8	0.8	2.1	0.7	0.0	0.2	0.0	0.0	0.0	0.6
1906-1912.....	13.0	0.2	2.2	4.6	0.6	2.4	4.5	1.2	2.9	5.1	0.7	2.8	3.8	0.0	1.1	1.5	0.2	0.1	1.2

Friant is about 203 miles above the mouth of the river with a drainage area above the station of 1,730 square miles.

Firebaugh is 43 miles below Friant with a drainage area above the station of 11,382 square miles. San Joaquin is 111 miles below Firebaugh and 49 miles above the mouth of the river. The drainage area above the station is 20,887 square miles.

The average fall per mile between Friant and San Joaquin Bridge is about 2 feet; from San Joaquin Bridge to the mouth of the river the fall is only a fraction of a foot per mile.

TRIBUTARIES OF TULARE AND BUENA VISTA LAKES.

There are several streams that enter the San Joaquin Valley from the Sierras south of the upper end of the San Joaquin River that are lost in Tulare and Buena Vista Lakes and the adjacent "Tules." They are the Kern, Kaweah, Tule, and Kings Rivers.

The Kern has its source at elevations ranging between 11,000 and 13,000 feet, with a drainage basin quoted as 2,500 square miles. It flows southwestward from the mountains and empties into Buena Vista Lake. During exceptionally high stages in this lake it has been known to escape thence through various sloughs northward into Tulare Lake. While the Kern has a heavy discharge when in flood, and has been known to cause disastrous inundations, much of its normal flow is now diverted in the vicinity of Bakersfield for irrigation purposes.

The mean annual precipitation in the Kern River Basin varies from less than 5 inches in the valley to as much as 50 or 60 inches in the higher regions. Above the 5,000-foot level it is mostly all in the form of snow.

Tule River Basin, north of that of the Kern, starts in the high mountain ranges of the Sierra Nevada at an elevation quoted as 9,000 feet and flows westward toward Tulare Lake, which it sometimes reaches, but the most of its normal flow is now diverted for irrigation purposes in the vicinity of Porterville. Its watershed is small, the total drainage being quoted as 350 square miles.

The Kaweah River flows southwestward from the Great Western Divide and at high stages reaches Tulare Lake. Its greatest elevation is about 12,000 feet, and its drainage basin is about twice that of the Tule. Below the foothills the most of its flow is used for irrigation. Both the Tule and Kaweah are subject to overflow and occasionally some damage is caused from floods in the vicinity of Porterville on the Tule and Visalia on the Kaweah. The mean annual precipitation in the Kaweah and Tule Basins varies from 8 or 10 inches in the valley to 30 or 40 inches in the higher regions. Heavy snow falls in the most elevated regions of both watersheds.

The Weather Bureau has recently established several stations on the Kaweah River, the most important being at Carter's ranch, near Three Rivers.

Kings River drains the western slopes of the Sierras between the Kaweah drainage and that of the upper end of the San Joaquin. It rises at an elevation of nearly 14,000 feet and flows southwestward to a point just north of Tulare Lake, where it separates, one part flowing southward into the lake and the other northward through Kings River Slough into the San Joaquin. This stream, however, has rarely augmented, to any great extent, floods in the upper San Joaquin for the reason that at high stages its greatest discharge follows its southern course to the lake. Its main stream is tapped just below the foothills and a large part of its normal flow is diverted for irrigation purposes. The mean annual precipitation in the Kings River Basin ranges from as much as 60 inches or more in the higher regions to as little as 8 inches in its lower reaches.

All streams lying south of the upper end of the San Joaquin River which have been ponded back by Tulare and Buena Vista Lakes will, no doubt, be used more and more for irrigation purposes as the cultivated area increases, which will ultimately result in the reclaiming of the entire Tulare Lake Basin.

Owing to the fluctuations of the water level of the Tulare Lake considerable interest has, during the past few years, been centered around this section. Although millions of dollars have been lost in farming ventures by the inundation of lands in the vicinity of the lake thought to have become permanently arable, farmers still look forward to the time when the entire basin, or the "Valley of the Tules," as it is sometimes called, will be added to the agricultural assets of the State.

No better description of Tulare Lake itself, and the conditions that have prevailed in that section during the past 10 or 15 years, can be found than that published by the United States Geological Survey in Water-Supply Paper No. 251, which is as follows:

Tulare Lake is a shallow body of water occupying the lowest depression in the Tulare Basin. The lake is rectangular in shape and its greatest length is from northwest to southeast. In November, 1907, when the margin was carefully determined, the lake had an area of 274 square miles, a maximum depth of 12.4 feet, and average length of 20 miles, and a width of 13.5 miles; the water's edge was 3 miles from the town of Corcoran, and the water surface about 12 feet below. The lake reached its greatest height in the summer of 1907, when it had a maximum depth of nearly 14 feet.

For the 25 years preceeding 1898 the lake level was steadily lowered, with only seasonal fluctuations. This lowering was brought about by the development of irrigation in the Tulare Basin, the water used for this purpose being diverted from the streams supplying the lake; but undoubtedly the chief factor in producing the subsidence was light precipitation. During this entire period the precipitation was generally below the normal, particularly during the several years immediately preceding 1898, and in that year the lake became practically dry, and after having partially refilled in 1901, it became completely dry in 1905. As the water receded

a constantly increasing area of exceedingly fertile land was uncovered. From time to time this land was leveed on the lake side and cultivated, until, in the early spring of 1906, the entire bed was under cultivation.

On March 15, 1906, the first water reached the lake bed at the mouth of Kings River and began spreading over a large area of bottom land, upon which stood a crop of wheat almost matured. A few days later water from the Kaweah and Tule Rivers reached the lake. Then began a steady rise which rapidly submerged an increasingly large area of wheat fields. On June 1, the water was 7 feet deep, and covered 200 square miles. On June 23, overflow from the Kern Basin cut through the sand ridge from the south and flowed into the lake, which, for a few days afterwards rose at the rate of 0.2 foot per day. On August 4 the water reached its greatest height for the year 1906, and the lake had an area of about 300 square miles and a maximum depth of 12.7 feet. The total rise of the lake in 1906 was 10.8 feet. From this date the lake slowly subsided until December, after which a rise began which continued until July, 1907, when the lake attained a maximum depth of 14 feet. Since that date it has been gradually subsiding.

The lake bed resembles a large flat saucer, the flat, level area in the bottom has an elevation approximately 180 feet above mean sea level and covers about 55 square miles. The lowest point on the crest of the delta ridge to the north is about 27 feet higher than the bottom of the lake. Natural overflow will not occur, therefore, until the lake has a maximum depth of nearly 30 feet and an area of nearly 1,000 square miles.

The lake receives practically all of its water from Kings, Kaweah, and Tule Rivers. The Kings River furnishes the largest quantity. During flood periods about half of the total flow below all diversions enters the lake. Under normal conditions all the water of the Tule River and nearly all of that of the Kaweah River is diverted for irrigation, and only a small quantity of water from these streams reaches the lake. The water from Kern River is stored in Kern Basin, except in years of great run-off. It is said that previous to 1906 no water had reached the lake from Kern River for 25 years. It thus appears that in years of great run-off, like 1906-7, there will always be a flow into the lake. Owing to variations in the overflow, therefore, and in evaporation, which amounts to about 4.5 feet a year, it is probable that the lake will continue to fluctuate very much as in the past, though possibly never reaching very high stages.

TRIBUTARIES OF THE SAN JOAQUIN RIVER.

All of the tributaries of the San Joaquin River rise in the high regions of the Southern Sierra and flow westward. Those which materially affect the flood situation in the floor of the valley take a course nearly parallel with the upper end of the trunk stream and join it at right angles at points below its elbow north of Mendota. Named in their order from south to north, they are the Merced, Tuolumne, Stanislaus, Calaveras, and Mokelumne Rivers. The Fresno and Cowchilla Rivers, while tributary to the San Joaquin, are of no importance so far as the flood situation of the San Joaquin Valley is concerned. The Fresno, however, has a fairly extensive watershed and, under the influence of heavy local rains, has been known to overflow a considerable area directly contiguous to its course; but its rise is practically coincident with the cause, making flood forecasts impracticable.

The Merced River drains an extensive section directly north of the upper end of the San Joaquin and joins the lower section of that stream at a point a few miles east of Newman. The drainage basin

of the Merced above the valley is quoted at 1,200 square miles. The most elevated region of its watershed is about 13,000 feet. The Yosemite Valley is wholly within the drainage basin of the Merced River.

A regular river and rainfall station is maintained on the Merced at Merced Falls, 35 miles from the mouth of the river. The drainage basin above the station is about 1,000 square miles. The mean annual precipitation in this basin ranges from 10 to 15 inches in the valley to 20 or 25 inches in the foothills. In the higher regions it amounts to 60 inches or more, much of which is snow, which melts during the latter part of May or the first decade of June, often resulting in freshets in the lower reaches of the river. While the greatest flow of the Merced is in May or June, sometimes in July, should warm weather be delayed, this only takes place in years of normal or heavy snowfall in the mountains. Heavy, warm rains occasionally occur during the winter months, and in March, in which case floods result in some of the sections contiguous to the mouth of the river.

The Tuolumne River flows southwestward from the high mountains nearly parallel with the Merced whose watershed bounds it on the south. It drains about 1,500 square

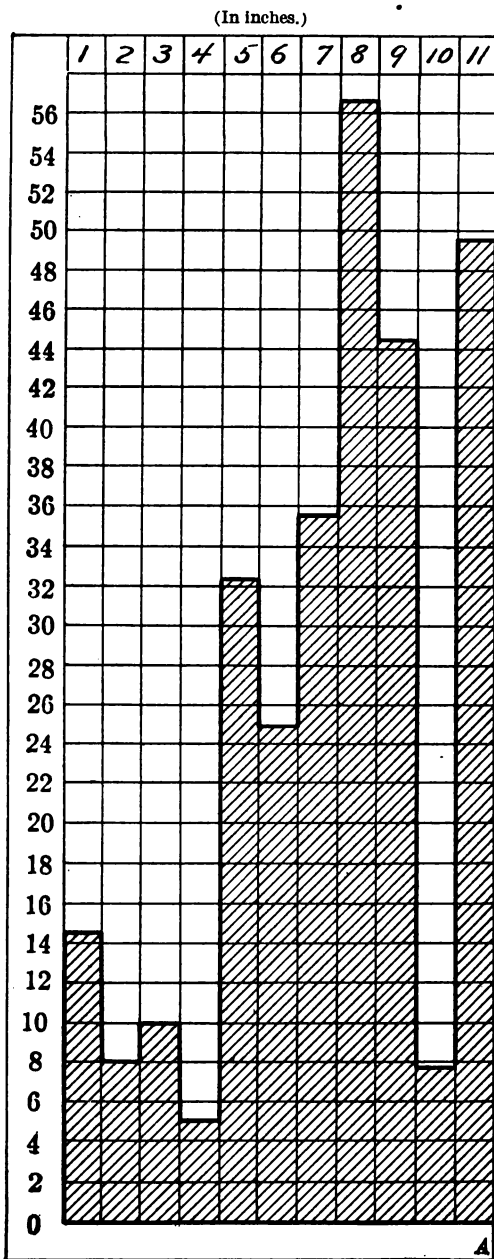


FIG. 15. Normal annual precipitation at 11 stations in the San Joaquin watershed. See page 56.

miles above Woods Creek, one of its most important tributaries. The highest point drained is about 13,000 feet on the North Slope of Mount Lyell. The mean annual precipitation in this watershed varies from about 10 inches in the valley to as much as 60 inches in the higher regions. It decreases rapidly as the floor of the valley is approached. Above the 5,000-foot level it is mostly all in the form of snow, which melts rapidly in the late spring and early summer and contributes to the usual June freshets in the lower San Joaquin Valley. Heavy rains are not uncommon during the winter months, or in March, in which case the river, which has a heavy fall, quickly responds and its flood wave hurries to the San Joaquin, which it joins a short distance west of the town of Modesto.

The stations and altitudes (see fig. 15) are as follows:

	Eleva- tion (feet).		Eleva- tion (feet).
1. Stockton.....	23	7. Sonora.....	1,825
2. Los Banos.....	121	8. Summerdale.....	2,270
3. Fresno.....	293	9. West Point.....	2,326
4. Bakersfield.....	394	10. Kernville.....	2,600
5. Mokelumne Hill.....	1,550	11. Crockers.....	4,947
6. Milo.....	1,600		

The United States Weather Bureau maintains a regular river and rainfall station at Jacksonville, just below the mouth of Woods Creek, which enables it to make accurate flood forecasts for Modesto and the regions adjacent to the mouth of the river, where a large area is protected by levees. The average fall of the Tuolumne from Hetchy-Hetchy to La Grange, 18 miles below Jacksonville, is 51 feet per mile. Jacksonville is 64 miles from the mouth of the river, and it has been estimated that a flood wave of 25 feet at this station will reach the San Joaquin in 11 to 13 hours, thus giving ample time for an intelligent river forecast for all sections subject to overflow. The greatest and most rapid rise on record for the Tuolumne occurred at Jacksonville between the 29th and 30th of January, 1911, when the river rose from 4.6 to 26 feet in 24 hours. The last-named stage was augmented by another foot rise by 7 a. m., January 31, when the river attained a stage of 27 feet, the highest on record.

The Stanislaus River drains a narrow basin between the Tuolumne and Mokelumne watersheds. The greatest altitude drained is quoted as 11,000 feet. The mean annual precipitation in the watershed of the Stanislaus ranges from 12 to 15 inches in the valley to as much as 50 inches or more in the mountains, where it is mostly as snow. This stream usually carries an increased volume of water during the late spring and early summer, as a result of melting snow, but heavy rains in the foothill sections are not uncommon during

the winter months causing floods in its lower reaches. The Stanislaus empties into the San Joaquin about 5 miles below the town of Tuolumne. The Weather Bureau maintains a river and rainfall station on this stream at Melones, 64 miles from the mouth of the river. The drainage basin above the station is about 562 square miles. Owing to the great fall of this stream from its source to its mouth, which is quoted as 70 feet to the mile, high stages in its upper parts usually reach the San Joaquin in about 10 hours, and its flood waves pass down the main stream several hours in advance of those of the Tuolumne and Merced.

The Calaveras River drainage is between that of the Stanislaus and the Mokelumne basins. This stream has the most restricted watershed of any in the San Joaquin Valley north of Kings River, and probably the smallest annual runoff per square mile of any river tributary to the Great Valley, except the Tule, north of Tulare Lake. The highest point drained is between 4,000 and 5,000 feet. The river flows southwestward from the foothills to the little town of Bellota, where it is deflected into a narrow channel known as "Mormon Slough," which empties into Stockton Channel.

The mean annual precipitation in the Calaveras watershed varies from about 16 inches in the vicinity of Stockton to 35 or 40 inches in the higher regions. Some snow falls on the summit of its basin but not in sufficient quantities to materially affect its flow. In fact, this stream is rarely kept alive much later than the 1st of July, after which it is usually dry until the first rains of winter. During the winter months heavy rains sometimes occur and occasionally result in damaging floods in the regions contiguous to Stockton, Bellota, and Linden. Stockton itself, or the greater part thereof, has been rendered practically immune from the ordinary floods of the Calaveras by the construction of a canal which diverts the flood waters of Mormon Slough into the lower Calaveras River, proper, a short distance below Stockton, whence they are carried to the San Joaquin. The flooding of Stockton and the adjacent section in 1909, before the completion of the diverting canal, and the great flood of 1911, when thousands of acres east of Stockton were under water, resulted exclusively from the overflow of the Calaveras. (See fig. 15, "Annual precipitation in San Joaquin Watershed.")

Two river and rainfall stations are in operation on the Calaveras, one at Bellota on Mormon Slough, 17 miles east of Stockton, and one at Jenny Lind, 13 miles above the point where the river flows into the Slough; and a rainfall station is maintained at San Andreas, 26 miles above Jenny Lind. Although the average fall of the Calaveras is nearly 15 feet per mile, and the fall between Bellota and Stockton is about 5 feet per mile, the advance of flood waves has heretofore been greatly retarded by spreading in the vicinity of

Bellota and Linden. With prompt service from river and rainfall stations it is possible to make timely forecasts for the greater part of the area subject to overflow. In fact the Bureau has not yet failed to do this at any time since the establishment of the river service.

Heavy rains in the San Joaquin Valley are usually coextensive with the watersheds of the Upper San Joaquin, Merced, Tuolumne, Stanislaus, and Calaveras Rivers, and result in the passage of four well-defined flood waves down the San Joaquin River, south of Lathrop. The crest of that of the Upper San Joaquin, and the discharge of the North branch of Kings River, usually reach the flat country in the vicinity of Mendota and Firebaugh about the time that those of the Merced, Tuolumne, and Stanislaus reach the lower San Joaquin. Should heavy rains continue, even for a few hours after the above-named streams have attained flood stages, the capacity of the trunk stream becomes overtaxed, and all points subject to overflow between the mouth of the Tuolumne and that of the Calaveras are liable to inundation.

The Mokelumne River flows southwestward from the Sierras and empties into the San Joaquin at a point about 25 miles northwest of Stockton. The greatest elevation drained by this stream is about 10,000 feet. In addition to numerous lakes and small creeks that feed the Mokelumne it has an important tributary in the Cosumnes, which joins it near Thornton, about 6 miles from Walnut Grove on the Sacramento. At flood stage the Cosumnes has a greater discharge than the Mokelumne itself above the point where the two rivers meet. The Cosumnes has the greatest fall of any river in the Great Valley, and is quoted as something over 80 feet per mile. The mean annual precipitation in the Mokelumne-Cosumnes watershed varies from something less than 20 inches in the valley to as much as 60 inches in the high mountain ranges in Alpine and El Dorado Counties.

The Weather Bureau maintains two river and rainfall stations on the Mokelumne; one at Electra, 70 miles from its mouth and 55 miles from its junction with the Cosumnes, and one at Bensons Ferry, a short distance below the point where the two rivers meet. The drainage area above Electra is 537 square miles; that above Bensons Ferry is about 1,200 square miles.

Floods rarely, if ever, occur in the Mokelumne as a direct result of melting snow, but heavy, warm rains during the winter months are liable to cause floods over an extensive area of low country below the mouth of the Cosumnes. During all previous floods of which there is an authentic record, and especially those of 1904, 1907, and 1909, a large area of country in the neighborhoods of Bensons Ferry and Lodi has been flooded. During the 1904 flood many of the levees

of the lower Mokelumne were swept away by the waters of the Sacramento, which escaped through what is known as the "Edwards break" and swept southward along the lowlands lying east of and parallel with the Sacramento River. The Edwards break occurred on the 27th of February, 1904, and three or four days later between 40,000 and 50,000 acres were under water between the Sacramento and the Mokelumne Rivers, with an estimated loss of over \$1,000,000 in Sacramento and San Joaquin Counties. The loss, however, was greater in the last named county along the South Fork of the Mokelumne.

In the 1907 flood the Mokelumne overflowed its banks above Lodi and Woodbridge, inundating many thousands of acres of land. In 1907 the floods of the Mokelumne were greatly augmented by the waters of the flooded Sacramento, which escaped eastward through a break in the levees near Courtland. It was the added water of the Sacramento River which resulted in the flooding of the Pierson District in 1909.

During the 1909 floods, while the Mokelumne was high, there was only one small break in its levees, which resulted in the inundation of perhaps a thousand acres.

The highest water on record, however, in the Mokelumne occurred in 1911, but all levees which had been strengthened held and there was little damage.

For much of the information regarding the Mokelumne floods the writer is indebted to Mr. Edward H. Barber, of Thornton, Cal.

FLOODS IN THE SACRAMENTO RIVER.

River readings were made at various points in the Sacramento River during the early days, but, until the river service was established by the Weather Bureau, the readings were in most cases indifferently made, and even the best of records were made without regard to any particular datum. The height of flood waters in former days have, however, at some points on the river, been fairly well established by landmarks, which furnish a basis of comparison with stages that have been recorded since the establishment of the service by the Government. Of course, conditions in the old days were vastly different from those that prevail at the present time. Before the settlement of the valley the river during high water roamed at will after it had emerged from its rocky canyons. Protected from the lowlands on either side only by its low banks, which sloped back into the floor of the valley, the river spread over large areas at stages that in these days would be called only moderate. It is believed that many of the "floods" that are associated with the early history of the Sacramento Valley would now pass unnoticed to the bay between levees.

There is, however, ample proof of the fact that there have been some high stages in the Sacramento River in the old days that would probably have been difficult to control even with the levee systems that now protect many of the agricultural districts and some of the smaller towns of the valley.

Regarding the various floods of the Sacramento and American Rivers in the city of Sacramento and its vicinity, history begins with that of 1850-51. Tradition, however, recounts an inundation in 1805, when it is said the entire Sacramento Valley was covered with water, except Marysville Buttes. This tradition was handed down by the Indians and at the time of the first white settlers in this section stories of the "great waters" were still extant.

The History of Sacramento County, by Thompson and West, published in 1880, contains some interesting accounts of the floods in the vicinity of Sacramento from 1850 to 1878. According to this history the flood of 1850 is the first of which there is an authentic record, and it refers to this flood as follows:

From January 9 to 17, 1850, the entire city of Sacramento was flooded.

In this connection it tells of heavy damage and some loss of life. Of course, the city at that time occupied only a small area, and while the damage was, no doubt, relatively heavy, the probability is that there was little to lose. That this flood was of some intensity is proven by the amount of rain that fell during December, 1849, and January, 1850. It was the flood of 1850 that first suggested the necessity of building levees around the city, and the introduction of this method of protection dates from that year.

The following is taken from the history of Sacramento County:

On March 7, 1852, another flood occurred at Sacramento, which leveled the most of the levees that had been built for the protection of the city.

During this flood, which must have come from the American River, historians of this section record the destruction of many bridges on this stream, especially those which spanned the South and Middle Forks.

On January 1, 1853, the city of Sacramento was again flooded, the water, according to history, rising to 22 feet above low-water mark. Little damage resulted from this flood, which seems to have subsided quickly, offering evidence of the fact that it came in from the American River.

From 1854 to 1860, inclusive, there are no records of floods in any part of the Sacramento watershed, and the record of precipitation during this period shows no heavy rainfall.

The history previously referred to states that on March 28, 1861, another flood of brief duration occurred on the American River, during which the river was 20 feet above low-water mark. On

December 9, 1861, the American is reported to have risen to 22.7 feet above the low-water mark, resulting in considerable loss.

The greatest and most disastrous flood of which there is any remembrance, and one that seems to have been general throughout the Great Valley, north of Kings River, occurred between January 9 and 12, 1862. The highest water at Sacramento during this flood has been quoted as 24 feet above low water. It has been stated that the American rose 60 feet above low-water mark, but the point



FIG. 44.—High water near Folsom in 1862.

where the measurement was made is not stated. The probability is that the American has been greatly overestimated and the Sacramento has been quoted too low.

According to measurements made in October, 1912, from the attested high-water mark of the 1862 flood made on an old stone stable, near where the Stockton and Coover mill stood on the left bank of the American River a mile and a half above Folsom, the American River at Folsom during that flood would have registered 38.3 feet on the present gage, or 11.5 feet above the 1907 flood.

Judging from all accounts of the 1862 flood it must have been the combined output of the American, Feather, and Yuba Rivers.

The rainfall of December, 1861, and January, 1862, in the vicinity of Sacramento aggregated 23.68 inches, 15.04 inches of which fell in the last-named month. As a result of this unusually heavy rainfall, which was undoubtedly coextensive with the entire Sacramento as well as the San Joaquin watershed, the American River from Folsom to Sacramento City was kept at flood stage until the approach of the Feather-Yuba and upper Sacramento discharge, a condition that had probably never before occurred in this section during its occupation by white settlers. All settlements in both valleys suffered greatly during the great flood of 1862, especially the city of Sacramento, the levee system of which was entirely leveled.

There were three floods in the upper reaches of the Sacramento during the winter of 1861-62. According to Capt. Lee, of Tehama, Cal., who has been connected with the river in various capacities for the past 60 years, and who is still enjoying life at the age of 86 years, the first flood occurred on December 9, 1861, when the river was higher than it had been for many years at all points between Tehama and Red Bluff. According to Capt. Lee, the water was over a foot deep in the streets of Tehama and many thousands of dollars worth of stock was drowned in the vicinity of that town. The second flood occurred on the 29th of December, 1861, following several days of unusually heavy rainfall. Cottonwood Creek was higher than was ever before known; Ludwigs Bridge, that spanned this stream, was carried away. This flood overtopped the banks in the vicinity of Red Bluff and completely inundated Tehama and other settlements along the Sacramento River. The third flood occurred on January 23, 1862, the water reaching the 29-foot mark on the Red Bluff river gage and flooding the warehouse on the east side of the river.

The historians of the Sacramento Valley agree that there were no floods of any importance from January, 1862, to February, 1878, notwithstanding the fact that some heavy rains fell during this interval, notably, November and December, 1864, January, 1866; December, 1867; January, 1868; December, 1871; and January, 1875.

From February 1 to 20, 1878, there were several floods in the Sacramento and American Rivers in the vicinity of Sacramento. On the first-named date the river rose higher than was ever before recorded, 26 feet above low-water mark. Some damage resulted from this flood, caused by the breaking of the levees near Lovdal's ranch, between the city of Sacramento and Suttersville.

The city of Sacramento has remained secure since 1878, notwithstanding the fact that the high stages previously recorded have been exceeded a number of times, notably, as follows: February 4,

1881, 26.6 feet; December 12, 1889, 27 feet; March 4, 1891, 27.6 feet; May 30, 1892, 27.2 feet; December 27, 1892, 28.6 feet; March 22, 1893, 26.5 feet; January 29, 1896, 26.6 feet; February 25, 1901, 28.2 feet; March 1, 1902, 28.2 feet; March 4, 1903, 27.6 feet; February 27, 1904, 26.1 feet; February 7, 1907, 27.2 feet; and January 17, 1909, 29.6 feet, the highest ever recorded.

While, as has been stated, the city of Sacramento itself has not been flooded in recent years, all of the high stages quoted above have resulted more or less seriously at many points up the river, especially in cases where vulnerable levees offered inadequate protection to lands in process of reclamation. For instance, the flood of 1881, is still remembered in the vicinity of Red Bluff and Tehama, where a large area of country was under water, causing heavy damage—loss of stock, destruction of bridges, etc. This flood was the result of heavy rainfall that was, for the most part, confined to the northern end of the valley, over 7 inches of rain having been recorded at Red Bluff during the three days ending January 30, 1881, and torrential rains, according to authentic reports, at points contiguous to the junction of the Sacramento and Pit Rivers.

The two most notable floods of the Sacramento and San Joaquin Valleys, from a pecuniary standpoint, were those of March, 1907, and January, 1909. It is thought that these floods were equally as widespread as was that of 1862, and the losses were, no doubt, far in excess.

In 1907 the land thought to be protected and that under process of reclamation aggregated a greater acreage than at any previous time in the history of the Great Valley. The same may be said of the flood of 1909, as the flood of this year occurred about the time when new levees had replaced those leveled two years previous, and many new reclamation districts besides. During both of these floods many levees were either badly damaged or totally destroyed, large areas rendered useless for immediate cultivation, bridges, both railroad and county, swept away, and many miles of county roads and railroad tracks rendered impassable.

The floods of 1907 and 1909 in the Sacramento and San Joaquin Valleys, and those of 1911 in the Lower San Joaquin Valley are the only inundations of which there is a complete record at all strategic points on the two trunk streams and their main tributaries.

THE FLOODS OF 1907.

The great floods that prevailed in the rivers of the Sacramento and San Joaquin Valleys during March, 1907, were, of course, the direct results of heavy, warm rains and melting snows that immediately preceded them.

64 FLOODS OF SACRAMENTO AND SAN JOAQUIN WATERSHEDS.

Table of daily precipitation at selected stations in the Sacramento and San Joaquin watersheds during March, 1907.

[In this connection see hydrographs, figs. 23 to 27, inclusive, for this period.]

Date.	Alturas.	Sisson.	Ken- nett.	Duns- muir.	Delta.	Shasta.	Red- ding.	Red Bluff.	Nim- shew.	Quincy.
Elevation, feet.....	4,460	3,555	616	2,285	1,138	1,049	552	307	2,500	3,400
Mar. 8.....	0.28	0.00	0.00	0.20	0.05	0.13	0.01	0.04	0.00	0.00
Mar. 9.....	.05	.45	.50	.66	1.10	.33	.67	.69	1.49	.60
Mar. 10.....	.05	.66	.0	.30	1.90	1.14	.49	.21	.33	.40
Mar. 11.....	.25	.00	.00	2.53	.90	.16	.18	.06	1.45	.60
Mar. 12.....	.00	.00	.00	.00	.10	.00	.00	.00	.00	.20
Mar. 13.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Mar. 14.....	.00	.00	.56	.00	.00	.00	.00	.00	.00	.00
Mar. 15.....	.00	.00	.00	.00	.00	.00	.00	.69	.00	.00
Mar. 16.....	.08	.00	.00	.00	.00	.38	.38	.65	1.40	.70
Mar. 17.....	.55	.00	.00	2.00	1.10	1.54	1.36	.62	5.54	5.30
Mar. 18.....	.75	3.55	.00	2.87	3.50	2.25	.88	.28	4.00	6.50
Mar. 19.....	.14	1.27	.54	2.72	3.50	1.03	.11	.00	3.02	4.40
Mar. 20.....	.15	2.25	2.44	2.00	3.10	.17	.07	.01	1.17	1.75
Mar. 21.....	.01	.60	2.00	.72	.80	.51	.23	.75	.43	.50
Mar. 22.....	.05	.60	1.56	.60	1.00	2.17	.19	.23	.75	.60
Mar. 23.....	.60	2.00	.82	.80	2.50	1.93	1.12	.05	2.00	3.60
Mar. 24.....	.05	.20	.82	.40	2.00	.62	.11	.06	.38	1.30
Mar. 25.....	.15	.40	.08	1.20	.10	.51	.09	.89	.62	1.40
Sum.....	3.16	12.0	9.32	18.8	21.6	12.9	5.89	5.23	22.6	27.8

Date.	Chico.	Fruto.	Colusa.	Oro- ville.	Wil- lows.	Nevada City.	Au- burn.	Fol- som.	Sacra- mento.	George- town.
Elevation, feet.....	189	624	60	147	136	2,580	1,360	111	71	2,650
Mar. 8.....	0.00	0.00	0.36	0.00	0.00	0.08	0.46	0.00	0.12	0.00
Mar. 9.....	.93	.23	.50	.30	.42	1.45	.00	.24	.40	.50
Mar. 10.....	.18	.36	.10	.86	.18	.51	2.35	.98	.15	2.31
Mar. 11.....	.25	.00	.00	.43	.06	.96	.32	.52	.06	.65
Mar. 12.....	.02	.00	.00	.22	.00	.15	.00	.20	.00	.75
Mar. 13.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.40
Mar. 14.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.20
Mar. 15.....	.00	.00	.26	.33	.00	.00	.00	.00	.04	.40
Mar. 16.....	.81	.22	.78	2.35	.51	.91	.16	.26	1.15	.30
Mar. 17.....	1.58	.45	.14	1.10	.70	2.47	2.08	1.42	.42	3.58
Mar. 18.....	.73	.40	.46	1.44	.13	3.34	.39	.10	1.74	1.06
Mar. 19.....	.36	.30	.12	.52	.05	3.63	3.11	2.08	.56	4.90
Mar. 20.....	.35	.25	.00	.08	.01	1.50	.88	.60	.06	1.48
Mar. 21.....	.22	.00	.22	.30	.15	.41	.36	.26	.15	.76
Mar. 22.....	.18	.00	1.02	1.32	.01	.58	.44	.26	.05	.91
Mar. 23.....	1.31	1.20	.20	.48	.78	3.43	.83	.68	1.46	1.78
Mar. 24.....	.06	.00	.08	.22	.15	.98	.00	1.28	.25	2.55
Mar. 25.....	.00	.30	.00	.11	.00	.90	2.94	.62	.01	1.85
Sum.....	6.98	3.71	4.24	10.1	3.15	21.3	14.3	9.50	6.62	25.4

Daily precipitation at selected stations in the San Joaquin watershed from Mar. 4 to Mar. 23, 1907.

Date.	Sanger.	Fire- baugh.	Merced Falls.	Friant.	Yosem- ite.	Jack- son- ville.	Me- lones.	La- throp.	Elec- tra.	Jenny Lind.
Elevation, feet.....	371	154	321	355	3,945	602	750	19	670	.....
Mar. 4.....	0.35	0.43	0.41	0.34	0.61	0.50	1.30	0.00	0.44	0.00
Mar. 5.....	.32	.14	.20	.44	1.88	.41	.24	.44	.42	.32
Mar. 6.....	.28	.05	.30	.38	.25	.30	.14	.00	.18	.26
Mar. 7.....	.00	.00	.00	.00	.05	.26	.26	.00	.04	.22
Mar. 8.....	.04	.00	.00	.00	.10	.28	.00	.00	.00	.00
Mar. 9.....	.00	.00	.00	.00	.01	1.46	.00	.00	.00	.00
Mar. 10.....	.00	.00	.33	.38	2.15	1.52	1.98	.60	2.20	1.10
Mar. 11.....	.56	.68	.60	.74	.92	.28	1.92	.06	.86	1.60
Mar. 12.....	.19	.10	.10	.12	.38	.00	.64	.10	.86	.48
Mar. 13.....	.00	.00	.00	.00	.00	.00	.00	.00	.16	.50
Mar. 14.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Mar. 15.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Mar. 16.....	.00	.00	.00	.00	1.40	.00	.00	.00	.00	.19
Mar. 17.....	.29	.08	.20	.40	2.61	1.30	1.88	.84	1.66	.70
Mar. 18.....	.00	.00	.00	.00	2.02	.01	.06	.00	.26	.08
Mar. 19.....	.10	.03	1.10	.28	1.85	2.48	2.06	.80	4.56	2.00
Mar. 20.....	.19	.00	.00	.02	1.15	.08	.00	.00	.44	.10
Mar. 21.....	.16	.41	.47	.00	.65	.90	1.04	.00	1.00	.40
Mar. 22.....	.16	.12	.32	.36	.85	.62	1.84	.48	.64	.35
Mar. 23.....	.38	.00	1.13	.06	.60	.00	.00	.00	.24	.46
Sum.....	3.02	2.04	5.16	3.52	17.5	10.4	13.4	3.32	14.0	8.60

FLOODS OF SACRAMENTO AND SAN JOAQUIN WATERSHEDS: 65

CALIFORNIA

Hydrographs, Sacramento River system, March, 1907.

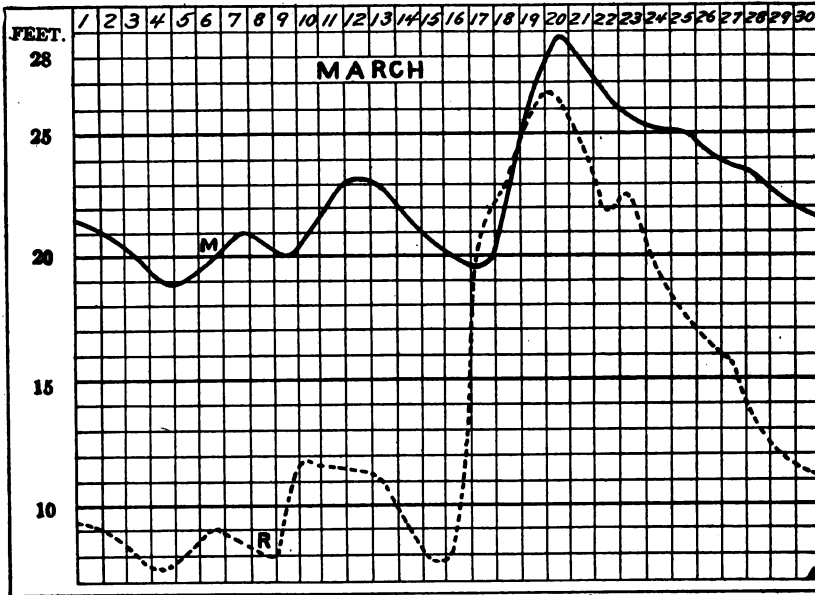


FIG. 23.—Hydrographs, March, 1907. M, Colusa; R, Red Bluff.

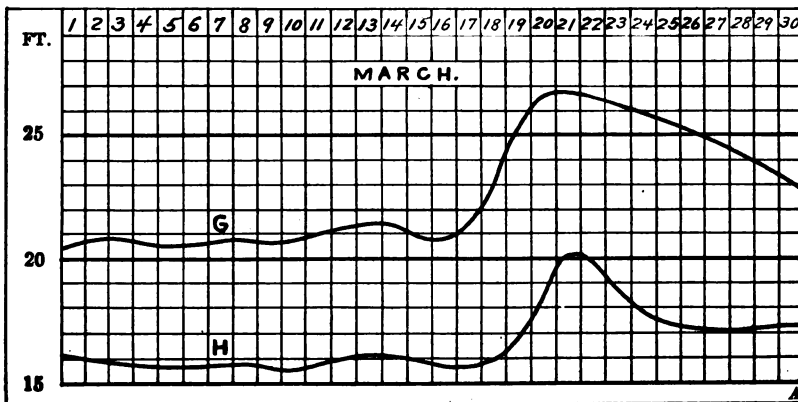


FIG. 24.—Hydrographs. G, Sacramento; H, Knights Landing.

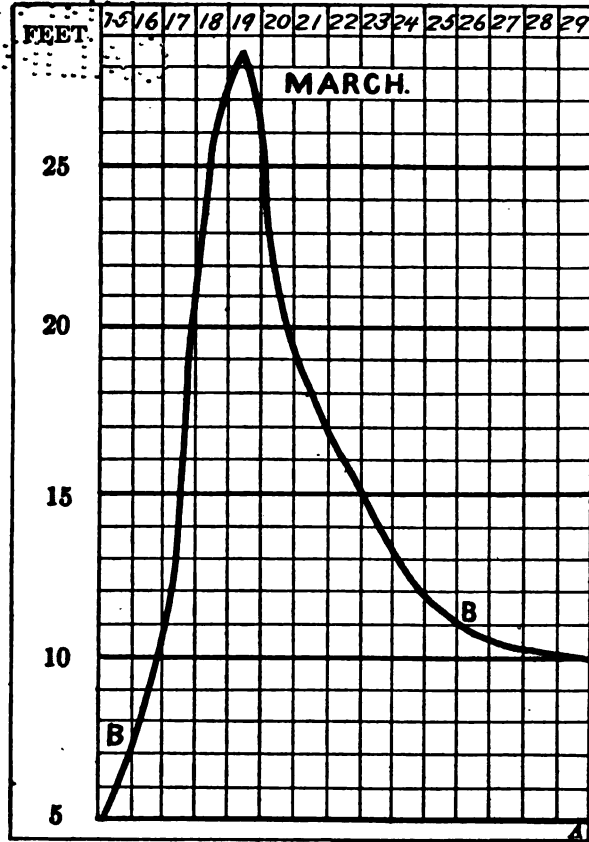


FIG. 25.—Oroville on Feather, March, 1907.

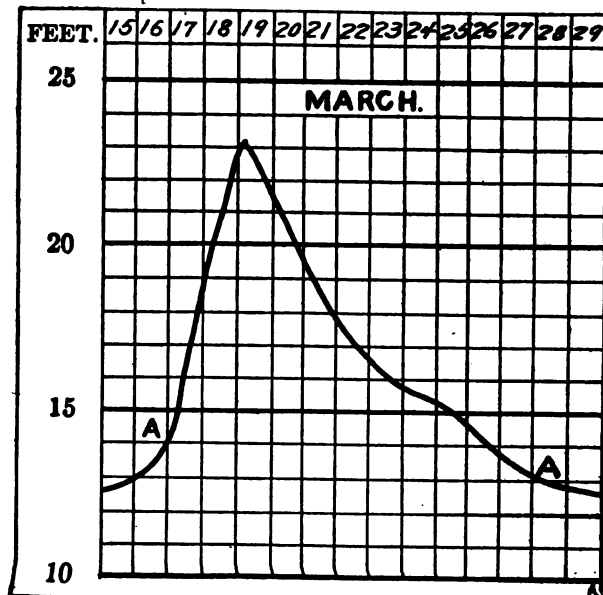


FIG. 26.—Marysville on Yuba, March, 1907.

Hydrographs, Sacramento River system, March, 1907—Continued.

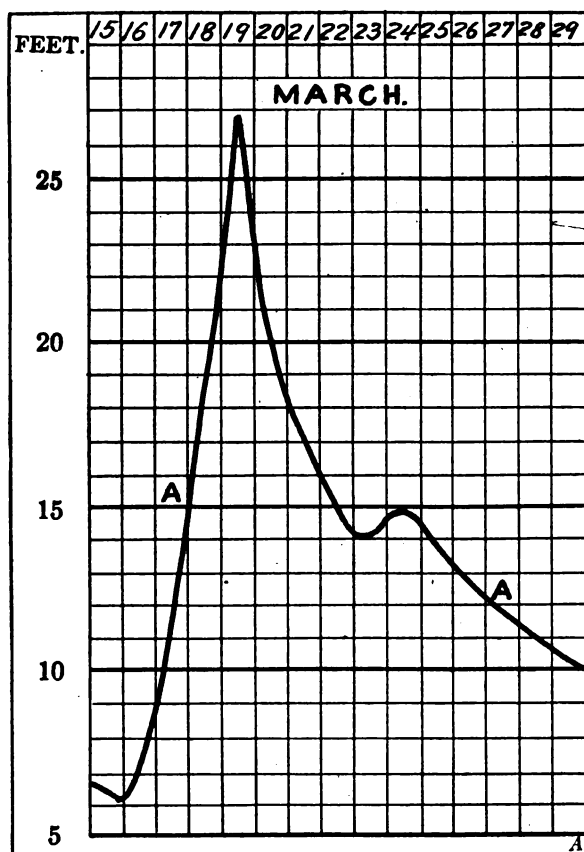


FIG. 27.—Folsom City on American, March, 1907.

68 FLOODS OF SACRAMENTO AND SAN JOAQUIN WATERSHEDS.

Conditions, however, during January and February of that year were largely responsible for the intensity of those in the watershed of the Sacramento. During the first days of January and the first decade of February the occurrence of heavy rains in the headwaters of the Sacramento drainage basin caused rapid rises in all streams, and, in some cases, floods and freshets. There were marked and dangerous rises at Folsom, on the American, on February 2, and at Marysville, on the Yuba, on the 3d, where stages of 21.2 and 22.2 feet, respectively, were recorded. From February 4 to 11, inclusive, high stages were also general in parts of the Sacramento River.

Before the rivers of the Sacramento watershed had recovered from the rains and melting snows of February, and while all flood basins on both sides of the Sacramento were practically full, another period of precipitation occurred between March 4 and 11. This condition resulted in raising the rivers to a point much beyond the stages usually maintained at this time of the year. From March 16 to 20, inclusive, there was another period of precipitation that was coextensive with the entire northern half of the State. At the same time temperatures were much above the seasonal normal in the high foothills and on the flanks of the mountains, which were thickly covered with the accumulated snows of the two preceding months. The effects of the heavy, warm rains and melting snows were almost immediate, and all the main rivers quickly responded to the increased run-off of the mountain feeders. At Kennett, on the Upper Sacramento, the river rose from 6.3 on the 17th to 18 feet on the 18th, and to 25 and 33.2 feet, respectively, on the two succeeding days. At Red Bluff the river rose from 7.9 to 20.7 feet between the 16th and 17th. On the 18th, 19th, and 20th, while the flood waters of the Upper Sacramento and Pitt Rivers were passing, stages of 22.8, 26, and 26.8 feet, respectively, were recorded at Red Bluff. At Colusa the river began rising rapidly during the night of the 17th, and by the morning of the 18th there was a gage reading of 22.7 feet, followed on the 19th and 20th by stages of 26 and 26.8 feet, respectively. The river rose slowly at Knights Landing, as the numerous breaks above tended to flatten out the flood wave before reaching that point. The river was high, however, and continued above the flood stage from the 20th to 24th, inclusive. By the morning of the 17th the river at Sacramento City had already become swollen as a result of the output of the American. On this date a gage reading of 20.9 feet was observed, after which the river rose gradually, averaging about 1 foot per day until the 20th, when it culminated in a stage of 26.9 feet. The breaking of the levees at many points above and below Sacramento checked a further rise at this point, but the river remained above the 26-foot stage for several days. The effects of the Sacra-

mento River flood were first felt at Rio Vista on about the 21st, after which the river at that point rose rapidly until the 24th, when it culminated in a stage of 17 feet, but a high stage was maintained for several days, due to the output of Yolo Basin through the sloughs that drain this basin into the Sacramento River.

The American at Folsom began rising on the night of the 16th, and by the morning of the 17th had risen from 6.2 to 12 feet. On the 18th it had risen to 18.6 feet, and by 7 a. m. of the 19th had reached the unusually high stage of 26.8, the highest ever recorded, except during the flood of 1862.

Coincident with the rise of the American, the Feather and Yuba Rivers rose rapidly. At Marysville, on the Yuba, the river rose from 14.1 to 20.1 feet from the 17th to 18th, and by the morning of the 19th had reached a stage of 23.3 feet, the highest observed.

At Oroville, on the Feather, the river rose from 5.1 to 11.6 feet during the 24 hours ending at 7 a. m. of the 17th. On the morning of the 18th it had risen to 23.6, and at 7 a. m. of the 19th the gage showed 28.2 feet, the crest of the flood at that point. As has been stated in another part of this paper, the flood waters of the Feather escaped through breaks in the levees at Hamilton Bend and rushed westward across country between Biggs and Gridley, thence through the lowlands north of Marysville Buttes and into the Sacramento River by way of Butte Slough.

While the floods were raging in the Sacramento Valley, like conditions were occurring in all sections of the San Joaquin north of the Tuolumne. The Tuolumne at Jacksonville reached a stage of 24 feet on the 19th, and a high stage was maintained on this stream from the mouth of Woods Creek to its mouth until the 21st, after which it fell sharply. The Stanislaus rose briskly from the 16th to the 21st, culminating at a stage of 12.2 feet, the highest on record. It remained at a high stage until the 26th. The Calaveras rose from 4.3 to 13 feet between 7 a. m. of the 16th and the corresponding hour of the 17th, and rushed into Mormon Slough at the rate of some 10 miles an hour and thence overflowing a large area of country. The Mokelumne rose from 8 to 13 feet during the 24 hours ending at 7 a. m. of the 19th. Below Bensons Ferry the flood waters of this stream were reenforced by a heavy swell from the Cosumnes. The combined run-off of the two rivers resulted in flooding something over 15,000 acres of land above Lodi. While the Mokelumne flood was at its worst, conditions were intensified by the breaking of the east side Sacramento levees near Courtland, through which the Sacramento River flood waters rushed into the lower Mokelumne Basin.

The San Joaquin River itself was at or above the flood stage from Mendota to the mouth of the river from the 19th to near the close

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of the month; this was especially so below Lathrop, where the highest stage on record, 19.2 feet, was recorded on the 20th. From about the 21st to the 28th the greatest damage was done in the delta lands of both trunk streams. (See list of islands and other tracts that were flooded, p. 91.)

FLOODS IN THE SACRAMENTO AND SAN JOAQUIN VALLEYS, 1909.

There were a series of floods in the central valleys of California from January 14 to 25, inclusive, and during the first decade of February, 1909. Those during the first-named period equaled in intensity the floods of 1907.

The first dangerous condition noted in connection with the 1909 floods was the heavy rainfall throughout the San Joaquin Valley on the 13th of January, and especially in the headwaters of the Calaveras River.

Table of daily precipitation at selected stations in the Sacramento watershed from Jan. 1 to 31, 1909.

[See hydrographs, figs. 28 to 40, for this period.]

Date.	Alturas.	Sisson.	Ken- nett.	Duns- muir.	Shasta.	Red- ding.	Red Bluff.	Quincy.	Chico.
Elevation.....feet..	4,460	3,555	616	2,285	1,049	552	307	3,400	189
Jan. 1.....	0.01	1.25	1.22	1.74	0.84	1.25	1.04	1.02	0.90
Jan. 2.....	.05	1.24	1.74	1.55	.93	.85	.17	2.43	.79
Jan. 3.....	.08	.00	3.20	1.96	.48	.39	.08	1.37	.82
Jan. 4.....	.00	.90	.04	.16	.38	.23	.73	.00	.08
Jan. 5.....	.36	1.19	1.20	1.14	2.32	2.24	2.00	2.58	1.60
Jan. 6.....	.18	.89	2.90	2.05	2.04	1.53	.00	1.35	1.07
Jan. 7.....	.30	1.86	3.10	2.02	3.87	1.07	.71	1.96	.32
Jan. 8.....	.60	.15	3.04	2.64	2.68	2.43	.34	3.10	1.25
Jan. 9.....	.70	.00	1.24	.63	.08	.00	.00	.54	.00
Jan. 10.....	.00	.00	.00	.00	.54	.00	.00	.00	.00
Jan. 11.....	.00	.00	.00	.00	.67	.00	.00	.00	.00
Jan. 12.....	.00	.02	.00	.00	.34	.11	.29	.10	.04
Jan. 13.....	.11	.62	.50	.50	1.40	.73	.23	1.48	.48
Jan. 14.....	.69	.65	3.00	1.84	1.87	1.65	1.42	3.20	.28
Jan. 15.....	.17	1.22	2.68	1.56	.91	2.11	1.36	2.77	1.12
Jan. 16.....	.17	.31	8.90	3.00	.71	.51	.10	1.90	.44
Jan. 17.....	.30	.08	.54	.80	2.04	.94	.06	.35	.15
Jan. 18.....	.07	.33	1.04	.49	1.30	.04	.02	.17	.10
Jan. 19.....	.04	1.28	.90	1.00	2.13	.93	.04	1.10	.50
Jan. 20.....	.05	2.25	2.42	2.49	2.94	.77	.69	2.45	.70
Jan. 21.....	.40	.65	.60	2.45	1.60	.22	.12	1.77	.46
Jan. 22.....	.17	.10	1.10	.48	1.17	.07	.04	.81	.10
Jan. 23.....	.00	.60	.06	.15	.97	.17	.08	1.09	.00
Jan. 24.....	.00	2.40	.50	1.10	2.28	3.45	1.43	.80	.75
Jan. 25.....	.01	.60	.50	1.30	.08	1.20	1.49	.83	.59
Jan. 26.....	.00	.00	3.10	.30	.15	.76	.47	.45	.80
Jan. 27.....	.01	.00	.30	.00	.00	.00	.00	.00	.05
Jan. 28.....	.00	.00	.00	.00	.00	.00	.00	.05	.00
Jan. 29.....	.00	.00	.00	.00	.68	.00	.00	.00	.00
Jan. 30.....	.00	1.30	.86	.30	.18	.58	.37	.50	.89
Jan. 31.....	.00	.83	4.00	.95	.38	.06	.14	1.00	.10
Sum.....	4.47	20.72	54.08	32.60	35.96	24.28	13.42	35.17	14.38

FLOODS OF SACRAMENTO AND SAN JOAQUIN WATERSHEDS. 71

Table of daily precipitation at selected stations in the Sacramento watershed from Jan. 1 to 31, 1909—Continued.

Date.	Fruto.	Colusa.	Oroville.	Willows.	Nevada City.	Auburn.	Folsom.	Sacramento.	Georgetown.
Elevation.....feet..	624	60	147	136	2,580	1,360	111	71	2,650
Jan. 1.	0.90	0.16	0.54	0.71	0.80	0.42	0.44	0.39	0.90
Jan. 2.	.33	.52	1.00	.12	.55	.20	.00	.28	.09
Jan. 3.	.60	.00	1.26	.48	1.57	.62	.44	.05	.91
Jan. 4.	.00	.40	.00	.08	.02	.00	.00	.21	.00
Jan. 5.	.70	1.04	.68	1.10	.97	.41	.26	.34	.62
Jan. 6.	1.05	.06	1.54	.74	1.79	1.45	.26	.35	1.87
Jan. 7.	.00	.62	.06	.13	1.02	.23	.20	.06	.50
Jan. 8.	.50	.04	1.40	.65	3.45	1.28	.92	1.05	2.40
Jan. 9.	.20	.00	.10	.05	1.10	1.59	.98	.06	3.28
Jan. 10.	.00	.00	.00	.00	.00	.00	.00	.00	.10
Jan. 11.	.00	.06	.00	.00	.05	.00	.00	.04	.00
Jan. 12.	.00	.22	.01	.13	.19	.18	.00	.65	.26
Jan. 13.	.20	.18	.76	.16	2.92	2.40	1.34	.37	4.12
Jan. 14.	.20	.68	.58	.28	4.48	2.95	.94	1.28	6.05
Jan. 15.	.40	.50	.70	.74	3.26	3.20	2.10	1.03	5.56
Jan. 16.	.80	.00	1.45	.70	1.62	2.00	1.60	.32	2.94
Jan. 17.	.00	.04	.02	.00	.31	.00	.00	.12	.28
Jan. 18.	.00	.06	.40	.00	.49	.70	.30	.00	.84
Jan. 19.	.00	.12	.24	.17	.52	.08	.00	.29	.04
Jan. 20.	.20	.58	.48	.51	2.31	1.20	.58	1.20	1.62
Jan. 21.	.65	.16	.85	.30	1.68	1.28	1.28	.41	2.70
Jan. 22.	.15	.00	.34	.08	.50	1.68	.32	.15	.69
Jan. 23.	.00	.06	.01	.01	.38	.29	.12	.00	.61
Jan. 24.	.30	.52	.00	.76	.18	.00	.02	.44	.26
Jan. 25.	.65	.68	.34	.21	.64	.42	.44	.12	.60
Jan. 26.	3.30	.18	.42	.87	.09	.08	.10	.12	.04
Jan. 27.	.10	.00	.08	.08	.13	.42	.22	.05	.35
Jan. 28.	.20	.00	.01	.02	.01	.00	.00	.00	.02
Jan. 29.	.00	.14	.00	.00	.00	.00	.00	.00	.00
Jan. 30.	.30	.24	.00	.27	.81	.00	.00	.27	.00
Jan. 31.	.00	.00	.00	.02	.01	.00	.48	.00	.71
Sum.....	11.73	7.26	13.27	9.37	31.85	23.08	13.94	9.65	38.36

Daily precipitation at selected stations in the San Joaquin watershed from Jan. 9 to Jan. 27, 1909.

[See flood charts for this period.]

Date.	Sanger.	Firebaugh.	North Fork.	Merced Falls.	Friant.	Yosemite.	Jacksonville.	Melones.	Lathrop.	Electra.	Jenny Lind.
Elevation.....feet..	371	154	3,000	321	355	3,945	602	750	19	670	.....
Jan. 9.	0.00	0.14	0.78	0.24	0.42	1.78	1.92	1.96	0.52	1.54	0.00
Jan. 10.	.00	.00	.20	.00	.10	.00	.12	.00	.00	.00	.00
Jan. 11.	.24	.00	.00	.26	.00	.00	.00	.00	.00	.00	.30
Jan. 12.	1.68	.34	.95	1.65	.38	.77	.16	.16	.32	.18	1.08
Jan. 13.	2.16	.43	4.43	.74	1.86	3.47	2.90	2.12	.54	2.56	1.60
Jan. 14.	.50	.06	4.42	.49	.88	3.17	1.76	4.56	.24	2.60	.68
Jan. 15.	.00	.00	.61	.17	.12	.49	.36	.56	.04	1.08	.24
Jan. 16.	.00	.00	.05	.00	.00	.67	.32	.58	.29	.42	.16
Jan. 17.	.00	.00	.10	.00	.00	.07	.04	.12	.00	.22	.00
Jan. 18.	.00	.00	.00	.00	.00	.00	.00	.06	.00	.58	.00
Jan. 19.	.00	.00	.00	.22	.00	.00	.00	.00	.00	.00	.55
Jan. 20.	.00	.16	.58	.79	.34	.79	.04	.70	.33	.76	.54
Jan. 21.	.94	.49	4.04	.35	.96	4.18	1.56	2.10	2.30	1.64	2.00
Jan. 22.	.00	.00	1.50	.40	.26	1.68	.60	1.04	.18	.82	.50
Jan. 23.	.00	.17	.30	.00	.26	.78	.70	.70	.12	.50	.15
Jan. 24.	.00	.00	.03	.68	.00	.00	.00	.01	.00	.06	.70
Jan. 25.	.00	.05	.47	.74	.18	.75	.96	.86	.08	.64	.70
Jan. 26.	.00	.75	.09	.70	.22	.60	.76	1.08	.20	.30	.30
Jan. 27.	.00	.79	.52	.00	.46	.64	.70	.62	.03	.42	.00
Sum.....	5.52	3.38	19.1	7.43	6.44	19.8	12.9	17.2	5.19	14.3	9.50

Hydrographs, Sacramento River system, March, 1907, and January, 1909.

Kennett, Cal.

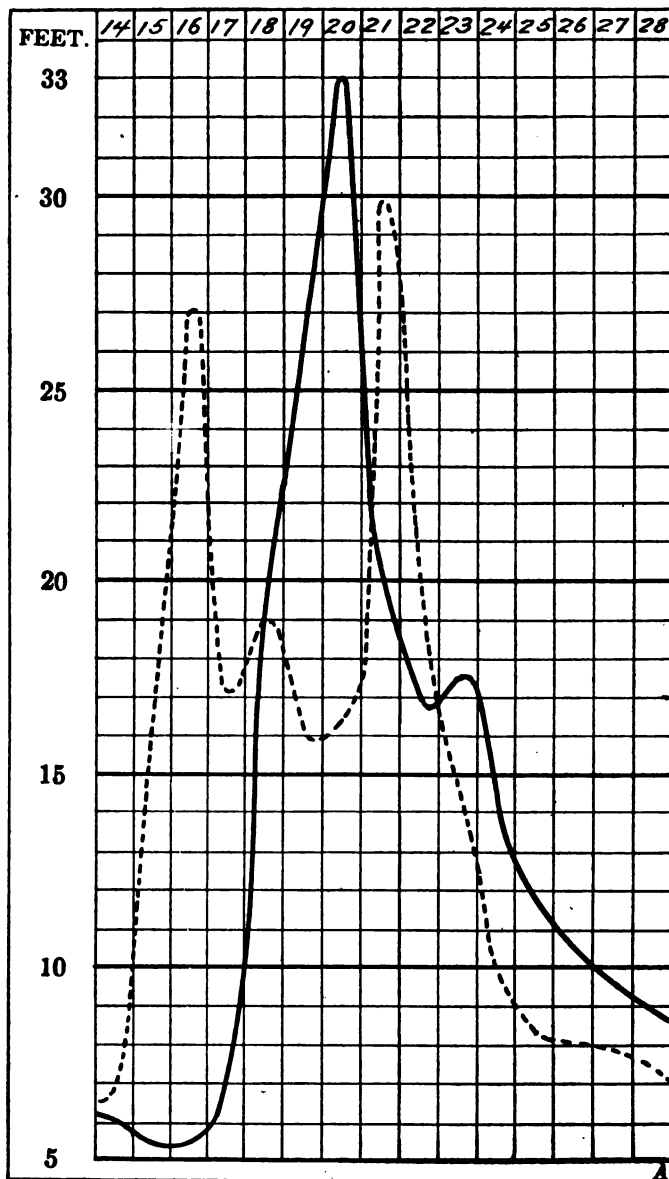


FIG. 28.—Solid line, March, 1907; dotted line, January, 1909.

Hydrographs, Sacramento River system, January, 1909.

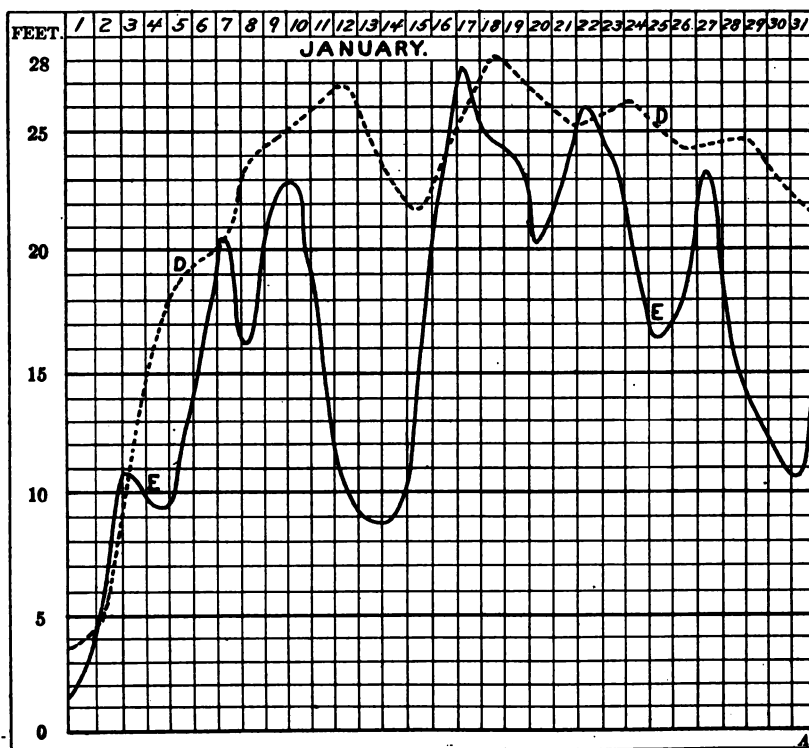


FIG. 29.—Hydrographs, January, 1909. D, Colusa; E, Red Bluff.

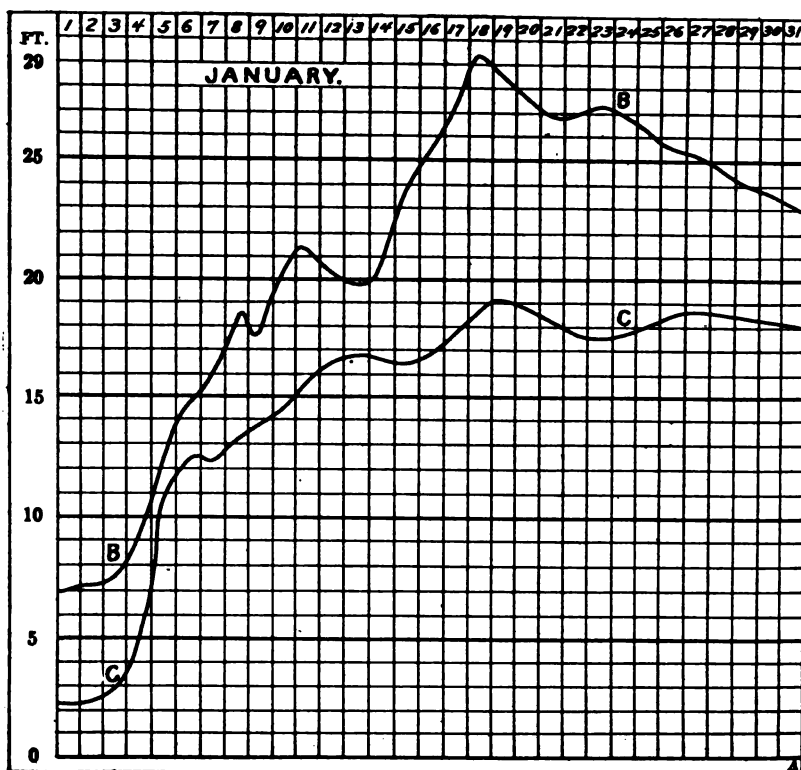
Hydrographs, Sacramento River system, January, 1909—Continued.

FIG. 30.—Hydrographs, Sacramento River, January, 1909. B, Sacramento; C, Knights Landing.

Hydrographs, Sacramento River system, January, 1909—Continued.

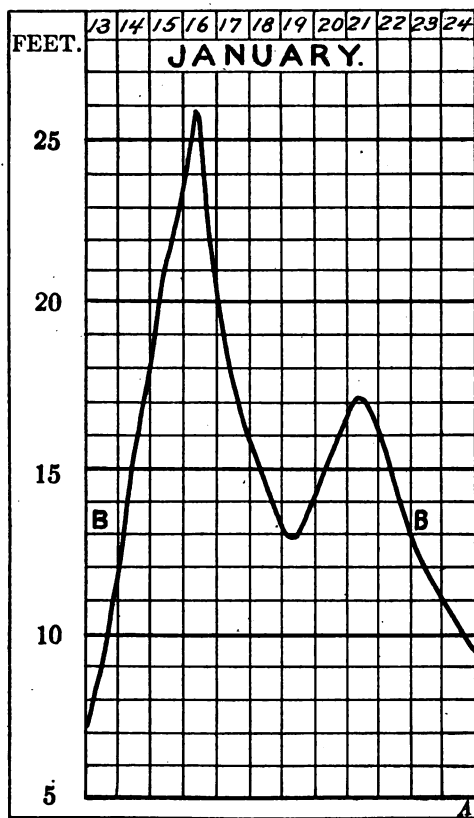


FIG. 31.—Hydrograph, Oroville on Feather.

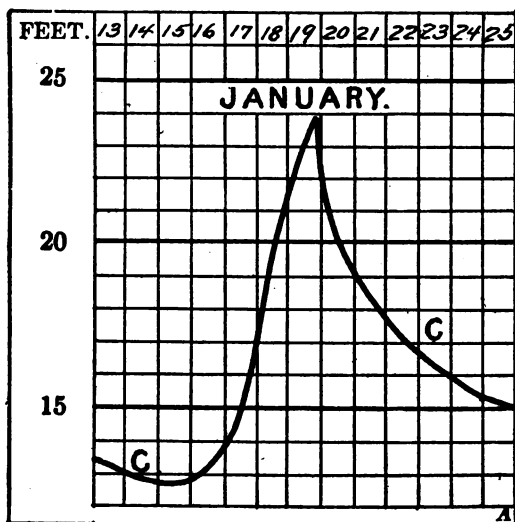


FIG. 32.—Hydrograph, January, 1909, Marysville on Yuba.

Hydrographs, Sacramento and San Joaquin River systems.

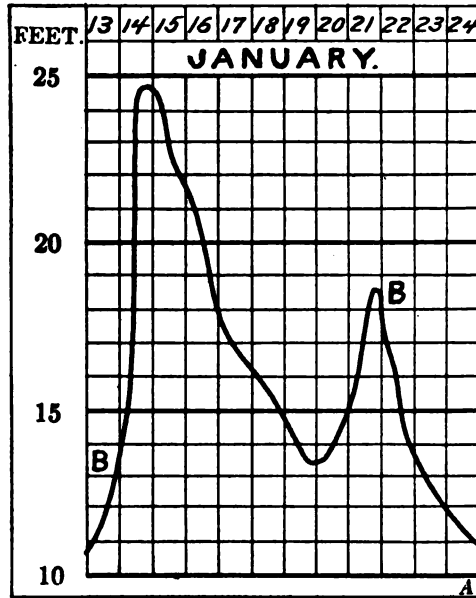


FIG. 33.—Hydrograph, Folsom on American, 1909.

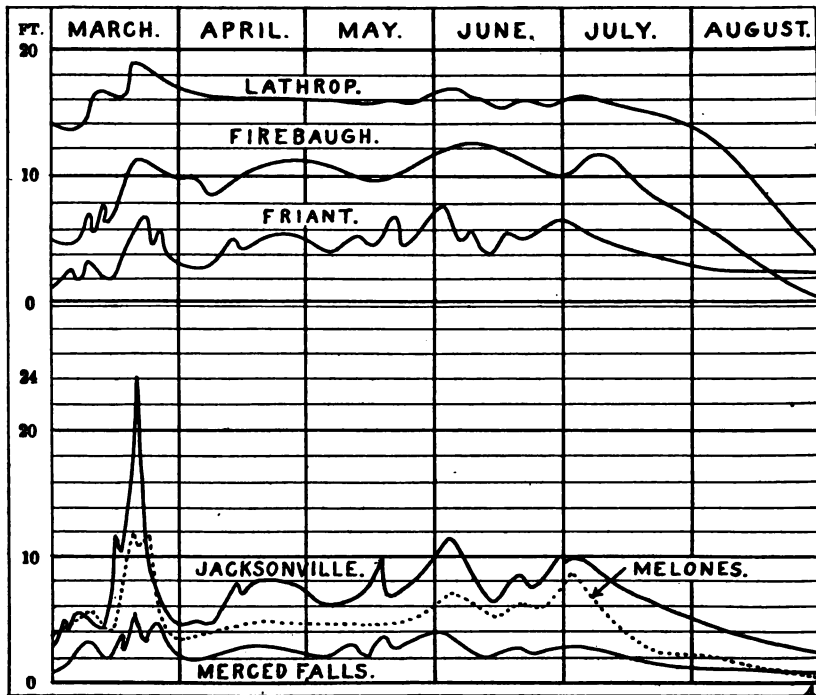


FIG. 34.—Hydrographs, San Joaquin River system, spring freshet, 1907.

Hydrographs, San Joaquin system, March, 1907.

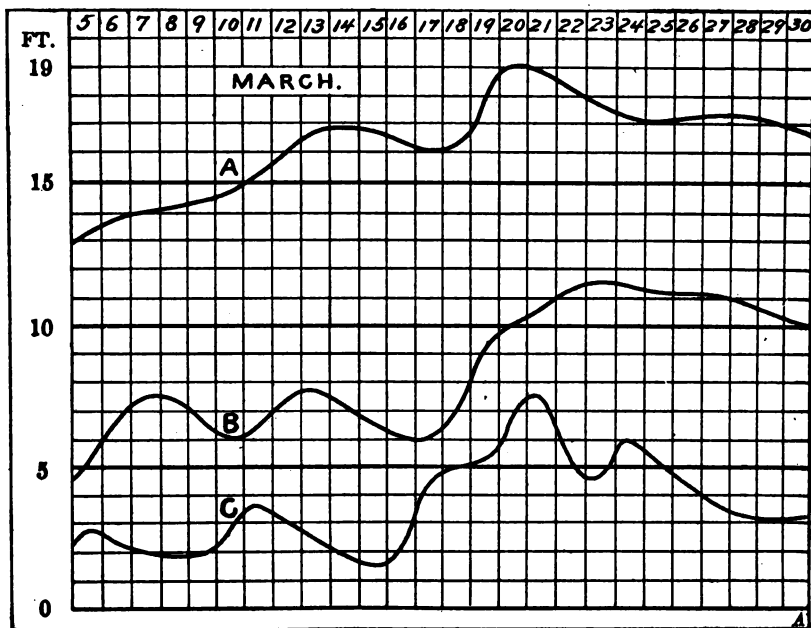


FIG. 35.—Hydrographs, San Joaquin, March, 1907. A, Lathrop; B, Firebaugh; C, Friant.

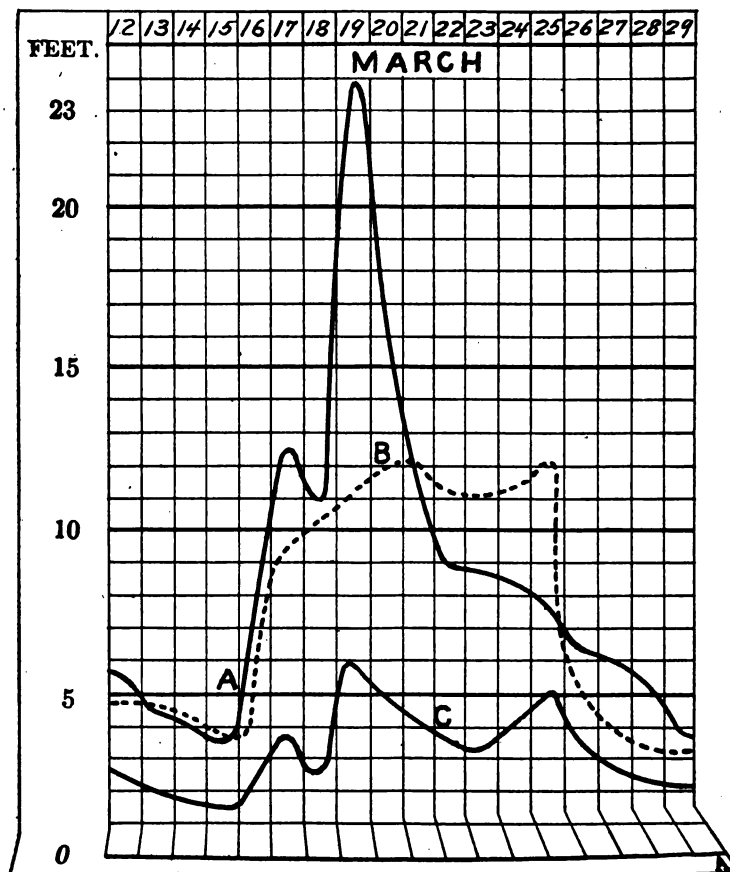


FIG. 36.—Hydrographs, March, 1907. A, Jacksonville; B, Melones; C, Merced Falls.

Hydrographs, San Joaquin system.

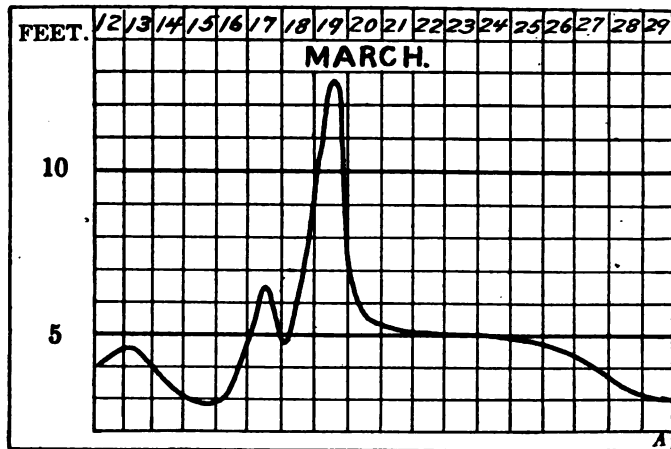


FIG. 37.—Hydrograph, March, 1907. Jenny Lind.

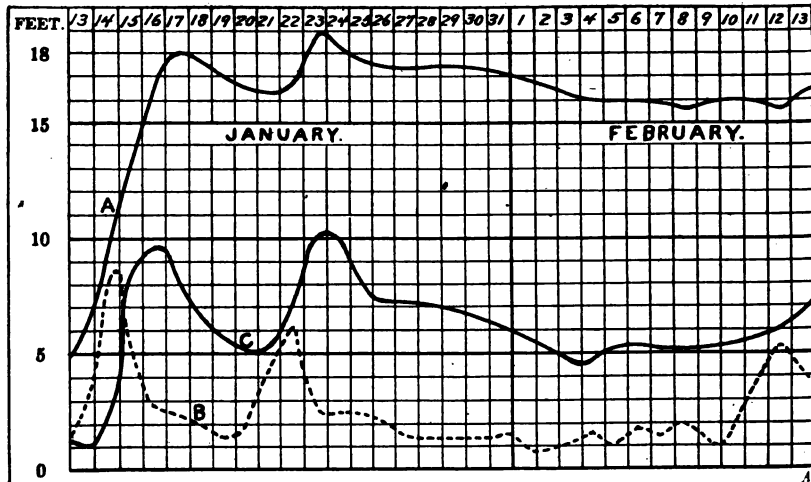


FIG. 38.—Hydrographs, San Joaquin, flood of 1909. A, Lathrop; B, Friant; C, Firebaugh.

Hydrographs, San Joaquin flood, January, 1909.

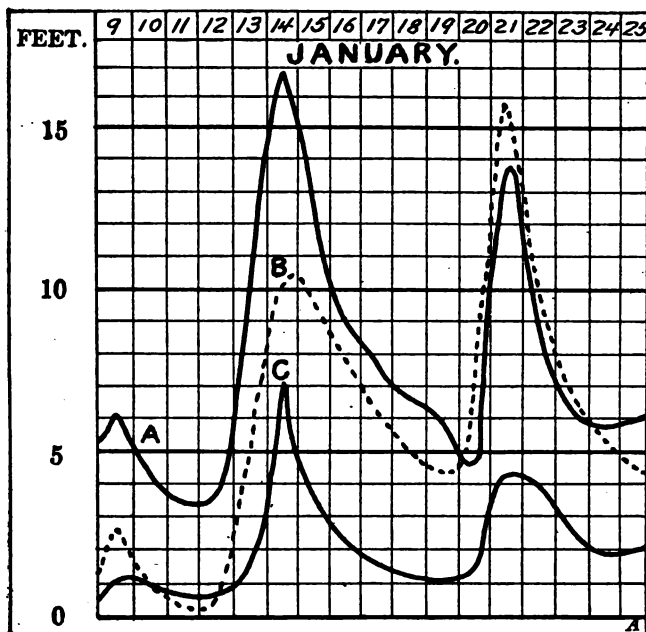


FIG. 39.—A, Jacksonville; B, Melones; C, Merced Falls.

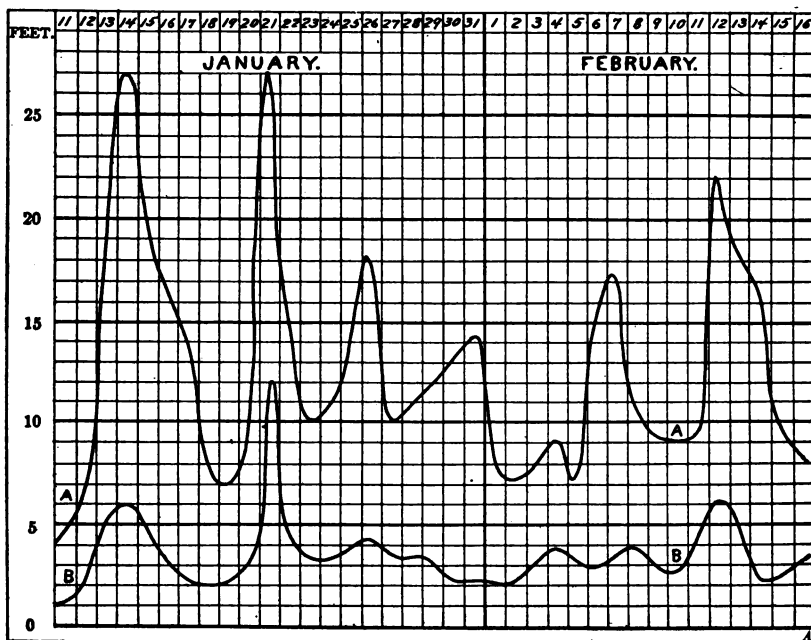


FIG. 40.—Hydrographs San Joaquin flood, January and February, 1909. A, Bellota; B, Jenny Lind.

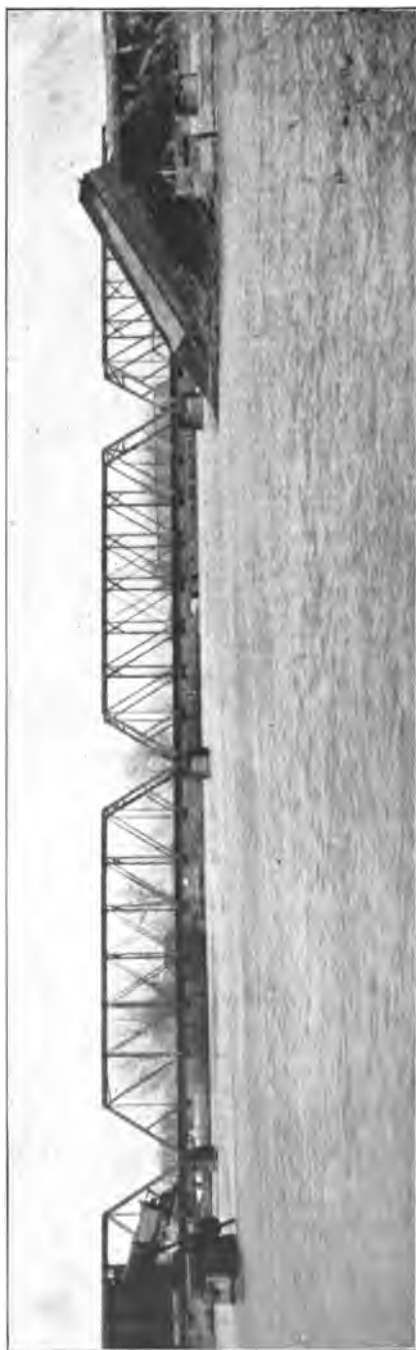
This table, in addition to its value in connection with flood reports of this period, is of interest in showing the daily precipitation in the Sacramento watershed during an exceptionally wet month.

At Bellota, where the Calaveras is led into Mormon Slough, the river rose from 5 to 20 feet from the 12th to the 13th, and on the 12th reached a stage of 27 feet, the highest ever recorded at that point, resulting in serious floods over a large territory contiguous to Stockton, besides flooding portions of the city itself. All rivers in the San Joaquin watershed rose beyond their flood stages between the 14th and 15th and the San Joaquin itself, below the mouth of the Tuolumne, remained above the danger point until near the end of the month.

On the 14th of January the situation in the Sacramento Valley in connection with the great floods that occurred later first became serious. In order that conditions in the valley at this time be understood, it may be stated that the first abnormal swell of the season occurred between Colusa and Sacramento City between the 8th and 11th of January. The southern edge of this swell had barely passed the last-named point before the American River, under the influence of heavy rains and melting snows in the large area drained by its numerous feeders, rose 13 feet in a night, and on the morning of the 14th was carrying stages ranging from 15 feet a few miles above its mouth to 24 feet near its first fork, a few miles above Folsom. During the early morning of the 15th the full force of the American flood wave reached the Sacramento River with a volume sufficient to dislodge some of the bridges that spanned the American near Sacramento. The gauge at Sacramento registered 24.9 feet at 7 a. m. of the 15th, but a higher reading must have occurred sometime between midnight and 4 a. m., or during the period of the passing of the American wave. The Sacramento continued to rise at Sacramento City until 12.30 a. m. of the 17th, when it reached a stage of 29.6 feet. This is the highest stage of which there is an authentic record. In the meanwhile the heavy rains throughout the drainage basins of both watersheds had swollen all watercourses beyond their carrying capacities, and many points on the main rivers were being flooded.

On January 16, it was estimated that the Sacramento River was carrying a flood wave from 1 to 2 feet above what may be termed the "danger point" from Red Bluff to Courtland, a distance of over 200 miles.

By the morning of the 17th the Sacramento River between Sacramento and Walnut Grove felt the relief afforded by the escaping waters through breaks in the west side levees, but the flooded area above, especially in the vicinity of Monroeville and St. John, was increasing. By 8 a. m. of this date the town of Broderick, just across the river from Sacramento, had mostly become inundated *from the back water of Yolo Basin.*



Courtesy Great West.

FIG. 45.—WRECK OF WESTERN PACIFIC BRIDGE OVER AMERICAN RIVER, JANUARY, 1909.

TO VNU
HANOI



Courtesy Great West.

FIG. 46.—FLOOD SCENE, 1909, IN YOLO BASIN, OPPOSITE SACRAMENTO.

TO: MR. J. EDGAR HOOVER
FROM: MR. J. EDGAR HOOVER



1000

TO VNU
ALBANY, NY

On the 18th the river at Sacramento had subsided to 28 feet, but by night of this date the flood waters of the Sacramento and those of the San Joaquin were rapidly approaching the delta. By the 19th the great volume of water that had accumulated in Yolo Basin began finding its way back into the Sacramento through Steamboat Slough and thence into the Lower San Joaquin through the various sloughs that connect the two rivers in the vicinity of the Lower Islands, so called.

From the 19th to the 27th inclusive flood conditions prevailed throughout all districts contiguous to the junction of the Sacramento and San Joaquin Rivers, and during this period many agricultural tracts and islands were either partly or wholly flooded. (See list of lands flooded in the "Island districts," p. 91.)

The January flood had barely subsided before heavy rains in the upper Sacramento Valley resulted in damaging floods in the valley north of Colusa. On February 3, all low lands lying between Tehama and Hamilton were under water, and the river between Redding and Monroeville, a distance of 99 miles, was carrying more water than during the floods of March, 1907, or those of January, 1909. In the vicinity of St. John, Monroeville, and Hamilton and thence eastward nearly to the town of Chico, it was estimated that fully 100,000 acres of land were submerged. Tehama was almost completely flooded, there being nearly 10 feet of water in some of the lower sections of the town.

There was little effect of the upper Sacramento flood felt below Colusa on account of the fact that the river flowed freely into the various basins through the breaks caused by the floods of the preceding month. Yolo Basin, however, was fuller than at any time during the previous floods, and it has been stated that the discharge of this sink into the Sacramento River above Rio Vista was sufficient to reverse the current of the Sacramento for a considerable distance above the mouth of Steamboat Slough.

From many reports that have been received from all sections covered by the floods those of 1909 were the most general and widespread of any previous inundations. They were as disastrous as any previous flood of which there is an authentic history, and probably more so, for the reason that, in addition to the large number of old levees broken, there were many new districts in process of reclamation which were inadequately protected by levees not yet completed. It has been estimated that over 300,000 acres of land were, at various times flooded during the January and February floods of 1909. The map reproduced in this bulletin as figure 48, p. 90, through the courtesy of the Great West, from data furnished by the bureau, shows approximately the area that was flooded in the Sacramento Valley during the floods of 1907 and 1909.

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THE FLOODS OF JANUARY AND FEBRUARY, 1911.

On January 30, 1911, heavy, warm rains began falling in the headwaters of the tributaries of the San Joaquin, which resulted in the greatest flood in the history of the Lower San Joaquin Valley.

Daily precipitation at selected stations in the San Joaquin watersheds Jan. 20 to Jan. 31, 1911.

[See hydrographs, figs. 41 to 43, for this period.]

Date.	Fire- baugh.	North Fork.	Merced Falls.	Friant.	Yosem- ite.	Jack- son- ville.	Me- lones.	La- throp.	Elec- tra.	Jenny Lind.
Elevation.....feet..	154	3,000	321	355	3,945	602	750	19	670	.....
Jan. 20.....	0.36	0.85	0.17	0.05	0.40	0.44	1.10	0.36	1.26	0.94
Jan. 21.....	.00	.23	.91	.34	.04	1.30	1.34	.72	1.34	.00
Jan. 22.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Jan. 23.....	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Jan. 24.....	.40	3.20	.74	.64	.90	1.04	1.28	.74	1.46	1.16
Jan. 25.....	.34	2.60	.77	1.28	.79	2.20	2.00	.82	1.60	.82
Jan. 26.....	.00	.00	.04	.12	.00	.32	.26	.12	.82	.46
Jan. 27.....	.00	.00	.04	.00	.00	.10	.22	.12	.62	.04
Jan. 28.....	.00	.35	.05	.02	.27	.20	.46	.00	.22	.20
Jan. 29.....	.18	2.12	.17	.20	.48	.46	.36	.32	.44	.40
Jan. 30.....	1.20	2.86	2.73	1.84	1.20	3.50	4.40	.92	3.42	2.40
Jan. 31.....	.60	1.57	2.30	1.08	.06	3.06	3.02	.55	2.80	1.62
Sum.....	3.08	13.8	7.92	5.57	4.14	12.6	14.4	4.67	14.0	8.04

About 24 hours after the beginning of the rains the flood waters of the Merced, Stanislaus, and Tuolumne Rivers had practically reached the main stream, and three flood waves of great intensity began moving down the San Joaquin. The combined force of these waves reached the lowlands in the vicinity of Lathrop and San Joaquin Bridge during the day of February 1, and by night of this date many thousands of acres of land became flooded. Many head of stock were drowned between Mendota and Lathrop, and in the vicinity of San Joaquin Bridge there were many residences either washed away or else undermined. It has been estimated that ten thousand or more acres were under water between Firebaugh and Lathrop. By the morning of February 2 the flood waters had spread over a large territory between Lathrop and Roberts Island, destroying a number of levees and inundating several thousand acres of reclaimed land. In the meanwhile the Mokelumne had poured its flood waters into the lowlands, doing considerable damage. During this flood the Calaveras overflowed its banks after reaching Mormon Slough and flooded several thousand acres of land between Bellota and Stockton. The city itself was probably saved from one of the most disastrous floods in its history by a diverting canal, which deflected the water of Mormon Slough and carried it down into the Calaveras proper below Stockton. It has been conservatively estimated that fully 75,000 acres of land were overflowed in the San Joaquin Valley between Stockton and Mendota and in the vicinity of Bellota and Linden during the floods of January and February, 1911.

Hydrographs, San Joaquin flood, January-February, 1911.

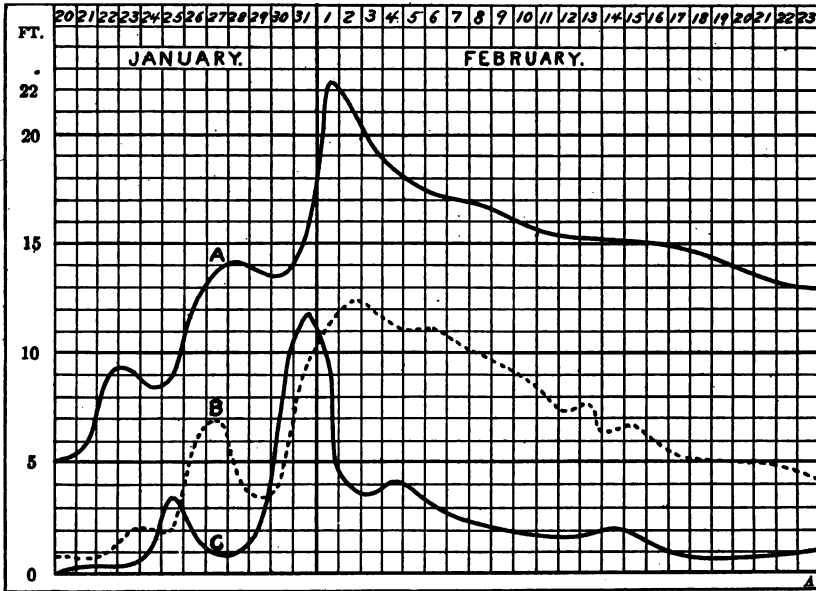


FIG. 41.—Hydrographs San Joaquin flood, 1911. A, Lathrop; B, Firebaugh; C, Friant.

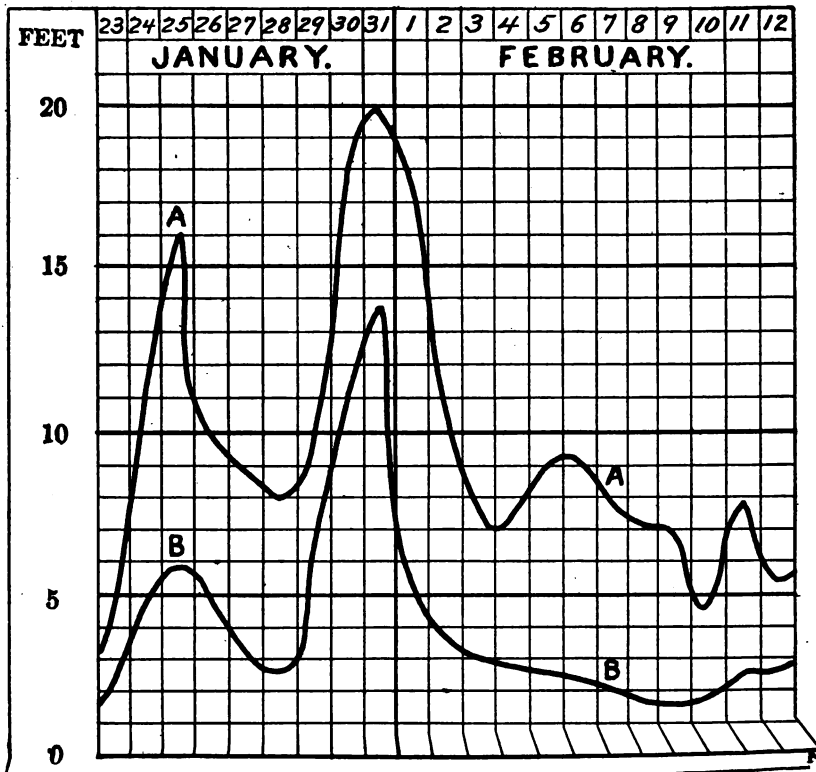


FIG. 42.—Hydrographs, January and February, 1911. A, Bellota; B, Jenny Lind.

Hydrographs, San Joaquin flood, January-February, 1911—Continued.

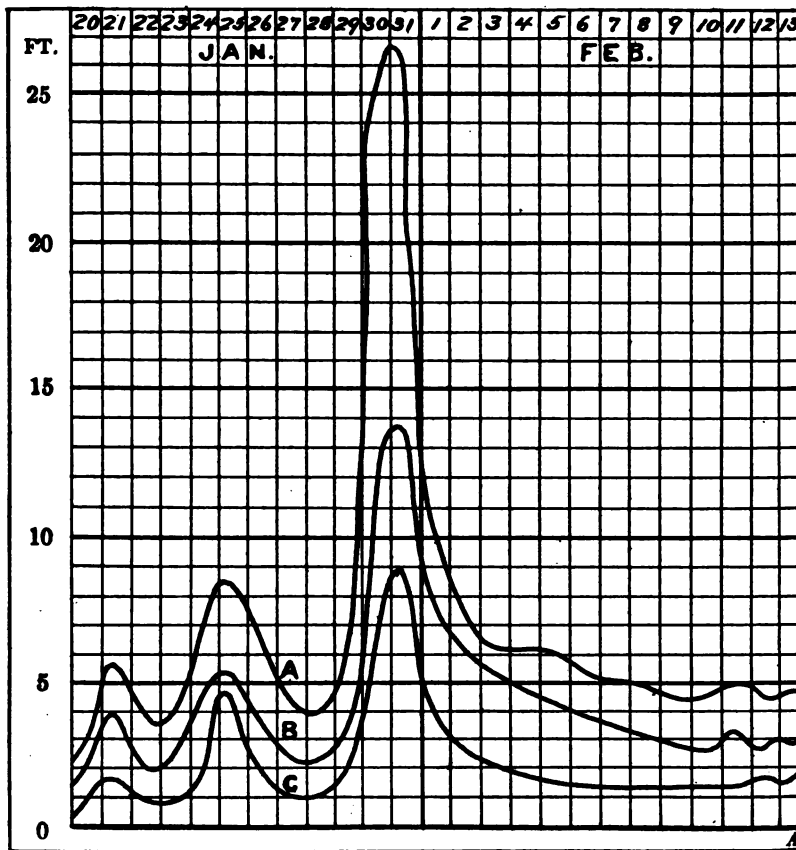


FIG. 43.—A, Jacksonville; B, Melones; C, Merced Falls.

River conditions in the Sacramento Valley again became critical in March, 1911, and a stage of 27.4 feet was recorded at Colusa on the 9th of that month. Heavy rains in the foothills that form the western boundary of Colusa Basin resulted in what is known as the "Trough" of this basin, reaching the highest stage ever before known. The water in this trough continued to menace the back levees that protected it from the foothill drainage, and finally, on April 25, 1911, those which protected reclamation No. 108 gave way, flooding 25,000 acres of land, the most of which was planted to grain, the entire crop being destroyed.

From April, 1911, to January 28, 1912, the date of this report, there have been no floods in the central valleys of California.

WARNINGS.

During all the floods that occurred in 1907, 1909, and 1911 the Weather Bureau issued warnings to every point involved from 12 hours to as much as 3 days in advance of the approach of the flood waters. Advices from the bureau regarding the great floods that prevailed in the delta lands of the Sacramento and San Joaquin Rivers in 1907 and 1909 not only indicated the intensity of the floods, but timed their approach within a couple of hours three days in advance.

The table below shows approximately the losses that were sustained in the Sacramento and San Joaquin Valleys during the floods of 1904, 1907, 1909, and 1911, and the amount that was saved by reason of the warnings that were issued by the Weather Bureau during those of 1907, 1909, and 1911.

LOSSES IN THE CENTRAL VALLEYS OF CALIFORNIA DURING THE FLOODS OF 1904, 1907, AND 1909.

From reliable reports, and from data which have been gathered from time to time during the past four years, it is estimated that losses due to floods in the drainage basins of the Sacramento and San Joaquin Valleys during the floods noted above aggregate over \$10,000,000.

The losses have been divided as follows:

Buildings.....	\$200,000
Lumber.....	75,000
Levees.....	3,500,000
Stock.....	200,000
County roads.....	1,000,000
County bridges.....	900,000
Railroads, including roadbeds and bridges.....	2,000,000
Crops destroyed.....	1,250,000
Damage to lands by erosion.....	500,000
Losses sustained by suspension of business.....	200,000
From all other causes.....	500,000
<i>Total.....</i>	<i>10,325,000</i>

The amount saved during the floods of 1907 and 1909 by reason of the timely warnings that were issued by the Weather Bureau aggregate close to \$2,000,000. This amount is quoted from estimates that have been received from all sections covered by the floods. It has been admitted that the amount saved would have been much greater had the warnings been heeded in all cases.

THE FLOOD PLANE OF THE SACRAMENTO RIVER.

In studying the tables of high stages in the Sacramento River at Sacramento City and at other points in the Sacramento Valley, it will be noted that the flood plane has become higher each year; that since the high water of 1850 almost each succeeding flood has been higher than that of its predecessor. In fact, the expression so often heard among river men to the effect that the rivers are rising higher each year has, up to the flood of 1909, become a recognized fact.

The ever-increasing flood plane in the Sacramento River at all points above the mouth of the Feather is, no doubt, due (1) to the increased height and strength of the levees along the river banks, and (2) the constant enlargement of reclamation areas. Both of these causes have, at most points, restricted the natural bed of the river to a channel at no time wide enough to carry its discharge under extreme conditions. The same may be said of the Lower Sacramento, American, Feather, Bear, and Yuba Rivers, except that the predominating cause in the raising of the high-water plane in these streams is the amount of mining débris that has been deposited in their beds. Until March 1, 1893, when a law was passed restricting hydraulic mining, millions of cubic yards of débris were annually being dumped into the upper reaches of these rivers; and, as it slowly found its way downstream, the finer particles advancing at moderate stages and the coarser and heavier matter moving farther and farther down with each succeeding high water or freshet, it not only became a serious menace to the agricultural lands on both sides of the rivers by causing overflows at moderate stages, but affected the navigability of the lower Sacramento River and for a time practically eliminated the Feather River from its mouth to its junction with the Yuba as a navigable stream.

According to notes kindly furnished by Mr. W. T. Ellis, jr., member of the State reclamation board, and for many years president of the Marysville Levee Commission, both the Feather and Yuba Rivers were navigable for a considerable distance above Marysville in the early days of the State's history. This is evidenced by the fact that in 1849 the steamer *Linda* came around the Horn from an Atlantic port and made a trip up the Yuba for a distance of 4 miles above Marysville. In notes, also furnished by Mr. Ellis, it is stated that the steamer *Phoenix* made a trip up the Yuba as far as Owsleys Bar

in 1854. In fact, it is a matter of authentic record that before the Feather and Yuba were filled with mining débris Marysville was the natural distributing point for the northern mining section of the State. It is of record at Marysville that on August 27, 1850, there were 24 sailing vessels in the "port" of Marysville, and on August 22, 1851, there arrived at Marysville 7 steamers with full cargoes. In the news columns of the Sacramento Bee of February 16, 1862, it is noted that the steamer *Defiance* made several trips to Oroville with freight during the months of January and February, 1862.

As an illustration of the depth of the bed of the river at Marysville before the filling in by mining débris, Mr. Ellis states that it is a matter of record that during the great flood of 1861-62, when almost the entire Sacramento Valley was inundated, including the city of Sacramento, the flood waters did not reach what was then and is still the main business portion of Marysville. While there are no records of the discharge of the flood waters at that time, they were, no doubt, much greater than those of 1907. It is of record that the rainfall at Nevada City during the winter of 1861-62 was 115 inches, and assuming that the same amount occurred at corresponding elevations in the Feather-Yuba watershed, makes it almost certain that the discharge of 1861-62 was far in excess of the 1907 and 1909 floods, when Marysville experienced considerable difficulty in protecting itself from overflow.

According to reports of engineers during the first 20 years of unrestricted hydraulic mining, from 1849 to 1869, the low-water plane of the Sacramento River at Sacramento City was raised 2.9 feet; that during the next 10 years, 1869 to 1879, the rise of this plane was doubled. Some engineers claim that the low-water plane from 1849 to 1900 was raised fully 7 feet. Col. Mendell, in his report, states that as a consequence of the elevation of the bed of the Sacramento River the tidal influence which in 1849 extended up as high as the mouth of the Feather, 25 miles above Sacramento, and was quite 2 feet at Sacramento, is now no longer noticeable above Hancock Shoals, 9 miles below Sacramento.

Capt. Thomas H. Jackson, United States Corps of Engineers, in connection with his examination and survey of the Sacramento River from its mouth to the Feather in 1908, states as follows:

A comparison of this survey with that of 1895-96 shows that the river is improving as a navigable channel; that it is recovering from the effects of hydraulic mining. It is estimated that the river bed for a distance of 14 miles below Sacramento has lowered 2 feet within the past 12 years. The American and Feather Rivers, however, are still full of débris, and the effect of the sand deposits in the American River on the Sacramento River are noticeable for a considerable distance below the mouth of that river, and the fact that these two rivers contain probably more than 500,000,000 cubic yards of material, all of which must eventually pass down the Sacramento River to Suisun Bay, must be borne in mind in any consideration of the improvement of the river.

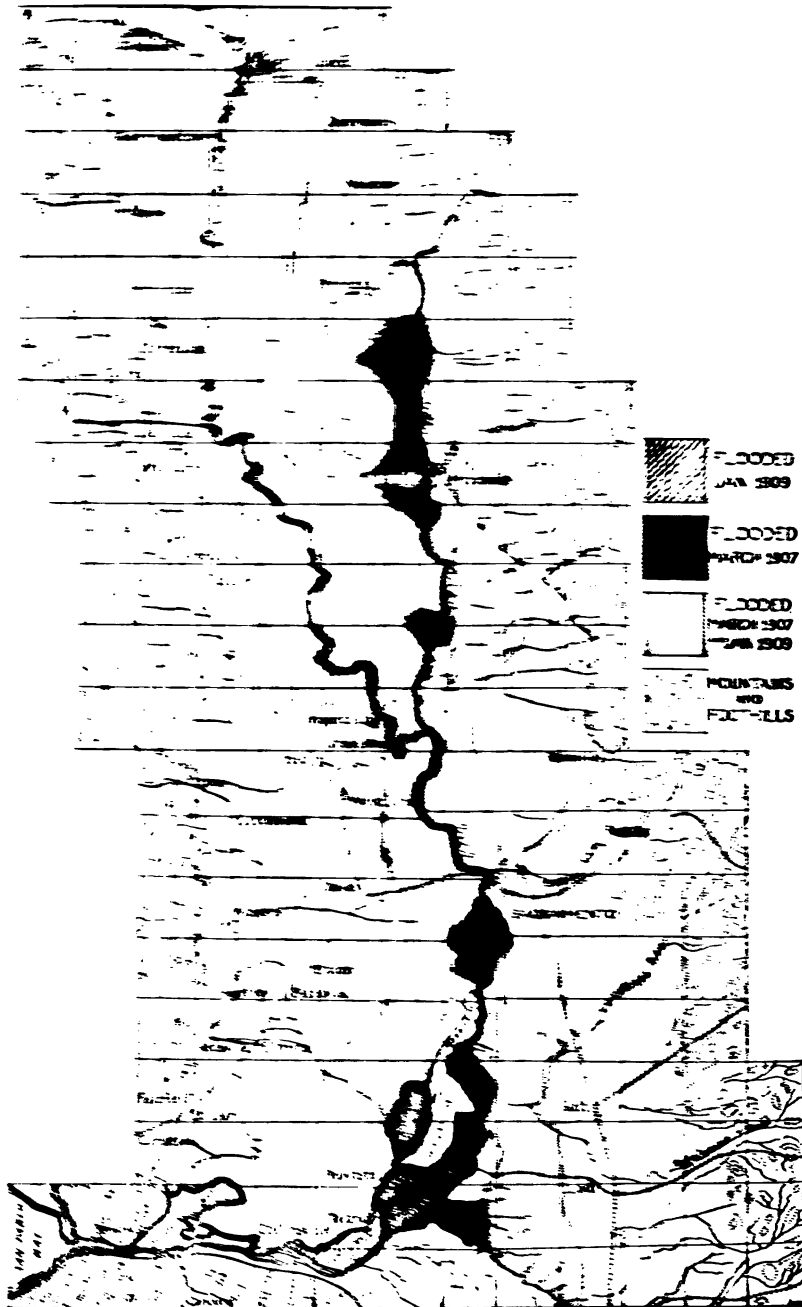


FIG. 48.—CHRONOLOGICAL RECORD OF SACRAMENTO VALLEY.

DELTA LANDS OF THE SACRAMENTO AND SAN JOAQUIN.

In the lower reaches of the Sacramento and San Joaquin Rivers are numerous low tracts of land and many islands, all of which have been built up by silt from both streams. Some of the islands are composed of a combination of silt and peat. The reclamation of these lands, which are the most productive on earth, has necessitated the erection of levees not only strong enough to withstand a long siege of high water, but also to resist the action of winds and tides, both of which are strong factors during periods of high water.

On account of the numerous islands that are separated from the mainland and the many tracts that are dissected by sloughs and other waterways, and the wide range of tides in the lower districts, no Weather Bureau gages have been established in the delta below Rio Vista. Mr. W. E. Meek, a prominent citizen of Antioch, with large agricultural interests in the island districts, made measurements in parts of the lower San Joaquin River during the floods of 1907, 1909, and 1911.

In comparing the floods in the delta of 1907 and 1909, Mr. Meek states that the highest water reached in 1907 was exceeded by that of 1909 in all of the lower districts. In the San Joaquin River above Stockton, however, the crest of the 1907 flood was about 0.5 of a foot higher. During the 1911 floods the water in the lower San Joaquin between Stockton and Mendota was between 2 and 3 feet higher than ever before recorded. But, as stated by Mr. Meek, it did not come within 18 inches as high in 1911 as it did in 1909 on the following-named islands: Andrus, Bradford, Jersey, Sherman, and Twitchel.

The following-named lands in the delta were flooded in 1907: Andrus Island,^a Bethel tract,^a Bouldin Island,^a Brannan Island, Burke tract, Byron tract, Clifton Court tract, Coney Island, Elmwood tract, Franks tract, Jersey Island,^a lower Jones tract, Lower Sherman Island,^a Moss tract, Ridge tract, Ryer Island, Sargent Burnhardt tract, Statin Island, Stone tract, Terminus District, Twitchel Island,^a Tyler Island, Venice Island,^a Victoria Island, and Webber tract, aggregating 130,744 acres.

CONCLUSION.

During the past few years large interests have recognized the ultimate value of all reclaimable lands in the central valleys of California. In the Sacramento Valley especially millions of dollars are now being applied to the work of reclaiming the various flood basins heretofore considered as waste land. According to the Report on the Control of Floods in the River Systems of the Sacramento and San Joaquin Valleys, published in 1911, there are 48 reclamation

^a Also flooded in 1909.

districts in the Sacramento Valley itself. Reports on 41 of these districts, with an area of 217,904 acres, showed on July 1, 1909, that 205,423 acres have been completely reclaimed and 99,376 acres partly reclaimed by the construction of 521 miles of levees. To these figures should now be added nearly 200,000 acres, as since 1909 the reclamation of Colusa Basin has been practically completed, about 12,000 acres on the west side of the river opposite Sacramento City have been reclaimed, 90,000 acres, comprising the American Basin and other low lands east of the Sacramento and between the Bear and American Rivers, are in process of reclamation, and tentative plans are afoot for the reclaiming of 60,000 acres within Sutter Basin.

Immense levees, practically impregnable, now skirt the Feather River from Vernon to a point near Marysville, and on the south side of the Bear River from its mouth to a point near Wheatland. These levees will not only confine the flood waters of the Bear and Feather Rivers, but will result in a reduction of the time it formerly took them to reach the main stream.

During the floods of 1907 and 1909 the overflow waters of the Feather, Yuba, and Bear Rivers escaped freely into Butte, Sutter, and American Basins, which not only tended to flatten out the flood wave of the Feather River below the mouth of the Bear, but delayed its approach to the mouth of the American River until the crest of the flood wave of this stream had passed into the Sacramento below Sacramento City.

Under present conditions it is estimated that flood water in the lower Feather River will reach the mouth of the American at least two hours earlier than heretofore, provided, of course, that it is not drawn off into Yolo Basin either by the breaking of the west side Sacramento River levees or through artificial by-passes of sufficient width and capacity to materially lower the water level in the main stream.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.

BULLETIN 44.
THE CLIMATE OF SAN FRANCISCO.

Prepared under the direction of WILLIAM L. MOORE, Chief U. S. Weather Bureau.

BY

ALEXANDER G. MCADIE,
PROFESSOR OF METEOROLOGY.



WASHINGTON:
GOVERNMENT PRINTING OFFICE,
1914.



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LETTER OF TRANSMITTAL

UNITED STATES DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU, OFFICE OF THE CHIEF,
Washington, D. C., December 3, 1912.

The honorable the SECRETARY OF AGRICULTURE.

SIR: I have the honor to transmit herewith a paper by Prof. A. G. McAdie, of the Weather Bureau, on the "Climate of San Francisco," and to recommend its publication as a Weather Bureau Bulletin, the edition to be 5,000 copies.

Very respectfully, your obedient servant,

WILLIS L. MOORE,
Chief United States Weather Bureau.

Approved.

JAMES WILSON,
Secretary.

THE CLIMATE OF SAN FRANCISCO.

INTRODUCTION.

San Francisco is in latitude $37^{\circ} 48'$ N., longitude $122^{\circ} 23'$ W. from Greenwich. The declination at the present epoch is 18° E. and the dip $62^{\circ} 12'$. The difference in time between San Francisco, Washington, and Greenwich is as follows:

San Francisco.	Washington.	Greenwich (mean civil time).
12 noon.....	15 hours (3 p. m.).	20 hours (8 p. m.)

When it is noon at San Francisco it is 9.29 a. m. at Honolulu; 3.37 a. m. of the next date at Hongkóng; 4.04 a. m. at Manila, and 5.19 a. m. at Yokohama.

In standard time, San Francisco is 3 hours earlier than New York, 2 hours earlier than Chicago, and 1 hour earlier than Salt Lake City. There is a difference of 9 minutes and 32 seconds between mean local time at San Francisco and one hundred and twentieth meridian time, the latter being the time in common use.

The city is built on the northern end of a peninsula and, except on the southern side, is surrounded by water. The Golden Gate is the water passage connecting the Bay of San Francisco with the Pacific Ocean, and it forms the northern boundary of the city. The Bay of San Francisco, extending north and south at an average distance from the ocean of 7 miles, bounds the city on the east. The bay, including its northern extension, San Pablo Bay, has an area of 420 square miles, and the length of the shore line is approximately 100 miles. The depth of the water varies from 2 to 69 fathoms. The eastern boundary of the bay, known as the Contra Costa and Alameda shores, is for the most part low lying, the land rising gradually for a distance of a mile or more and then abruptly forming the Berkeley Hills. Farther east Mount Diablo rises to a height of 3,849 feet, the summit of which can be plainly seen from the hills of the city, although distant 32 miles.

In the bay there are many islands, the most prominent being Angel Island, Yerba Buena, and Alcatraz.

The northern shore line is rugged and the land rises abruptly from the water. The Sausalito Hills have an average elevation of 110 meters (360 feet), and back of these Mount Tamalpais, 14 miles distant from the city in an air line, reaches an elevation of 792 meters (2,596 feet).

San Francisco covers an area of 46.5 square miles. Within the city limits are numerous hills, varying in elevation from 46 meters (150 feet) to 286 meters (938 feet). The highest elevation is Mount Davidson, 938 feet; followed closely by Mount Sutro, formerly known as Blue Mountain, 920 feet; the South Twin, 919 feet, and the North Twin, 919 feet.

HISTORY OF THE RECORDS.

Thomas Tennent, Dr. G. H. Gibbons, Dr. T. M. Logan and Mr. John Pettée kept records of rainfall and temperature for many years, and through their labors it has become possible to compile tables of these data covering a period of 63 consecutive years, the record beginning September 1, 1849. The thermometers used were of the self-registering pattern and were exposed on the north side of building on supports 10 inches distant from the wall and 6 feet above the ground. The instruments were at a later date compared with Weather Bureau instruments and found to be approximately accurate. The rainfall records obtained by Mr. Tennent at the foot of Market Street cover a period of 22 years, from September, 1849, to December, 1871. A 3-inch gauge of the type known for many years as the Tennent gauge was used. The catch of this gauge was carefully compared with the catch of the 8-inch Weather Bureau gauge and the differences were found to be small. Official records began when the Signal Service Office was established in the old Merchants Exchange Building, the first observation being made February 2, 1871. The office was moved to the Phelan Building September 4, 1890, and to the Mills Building November 1, 1893. After the earthquake and fire of April 18, 1906, the office was reestablished in the new Merchants Exchange Building, now known as the Chamber of Commerce. From April 19 until September 30, 1906, observations of temperature and rainfall, pressure, wind direction, and sunshine were made at No. 3014 Clay Street.

The instruments are now exposed on the roof of the 14-story building at No. 431 California Street. The portion of the roof in use has a width of 122 feet and a depth of 62 feet. The anemometer cups are 204 feet above the street; the rain gauge is 191 feet and the instrument shelter 198 feet above the street.

The station elevation of the barometer is 147.3 feet above the reference plane or city base, which in turn is 8 feet above mean sea level. The actual elevation of the barometer is 207.5 feet above sea level or 52.2 feet higher than the level used as a station elevation.

Extra instruments are exposed on the floor of the Chamber of Commerce and in addition a continuous record of the outside, or street temperature, is obtained. There is also a kiosk in Union Square Park, near the corner of Stockton and Post Streets, with instruments for recording temperature, rainfall, percentage of saturation, and pressure.

CONTROLLING FACTORS OF THE CLIMATE.

A clearer understanding of the problems connected with the weather of San Francisco can be had by considering the general topography of the section, rather than that of the city itself. The entire district is one of marked contrasts in air drainage. Strong surface currents of air will at times flow in from the sea through the Gate toward the Great Valley, while at other times these currents will be reversed in direction. The factor that exerts the greatest influence in controlling the weather of the San Francisco Bay section is the proximity of the ocean. The factor of next importance is the prevailing drift of the surface air from sea to land during summer months and from land to sea during winter months. A third factor is the diversified topography favorable on the whole for local circulation and consequently so-called local climates. A fourth factor is the general pressure distribution over the northwestern portion of the continent and the North Pacific Ocean. In a normal winter the Aleutian low extends from latitude 40° N. to 60° N. and from longitude 130° W. to 140° E. Variations in the position and intensity of this low are found to bear definite relation to the amount and frequency of rain. During summer months the Aleutian low practically disappears. The continental high and also the Pacific high play important rôles in connection with the strong northwest winds of summer on the California coast. For a discussion of the general relations between wet and dry seasons and the displacements of pressure areas or centers of atmospheric action, the reader is referred to Bulletin L, "Climatology of California," or to the Monthly Weather Review, April, 1908, in an article entitled "Forecasting for the Pacific Coast."

STORM FREQUENCY.

Compared with other portions of the United States, the San Francisco Bay section has comparatively few storms. This is because most of the recognizable disturbances pass far north of this section. Except in winter very few low pressure areas move from the ocean across California, as nearly all the storms that enter the United States from the west pass far north of central California. Since 1850 there have been during the months of June, July, and August but 13 storms of the character mentioned above. During September, 14 such disturbances have been noted in the period of 63 years, and of these the most important was the storm of September 22-26, 1904. This storm is worthy of special mention as it stands unparalleled in the history of summer and early fall disturbances. In four days 5 inches of rain fell, whereas the normal rainfall for the whole month of September is 0.30 of an inch. The relative frequency of storms increases with the advent of winter. During October there have been 40 disturbances; during November 60; and during December

January, and February about 200 per month for the total period of 63 years. Occasionally there will be a winter month without a single disturbance, as was the case in December, 1876, and February, 1864. March is a month of moderate frequency, April a month of occasional storms, and May of few storms.

PRESSURE.

The annual sea-level pressure at San Francisco as deduced from records covering a period of 38 years, 1873 to 1911 (1906 missing), is 30.027 inches. The lowest sea-level pressure recorded is 29.10 inches, which occurred February 22, 1891. The next lowest pressure, 29.23 inches, occurred March 10, 1904. The highest sea-level pressure, 30.60 inches, occurred December 23, 1905. The absolute range is 1.50 inches, and the mean annual range, 0.85 of an inch. The pressure is lowest during the summer months, averaging 29.92 inches, and highest in the winter months, averaging 30.10 inches. The daily pressure is lowest about 5.30 p. m., with a second minimum at 4 a. m., and highest at 10 a. m., with a second maximum at 11 p. m.

TEMPERATURE.

San Francisco has a comparatively small range of temperature. The annual mean, based upon records covering a period of 40 years, 1871 to 1911, and obtained from the mean of the daily maximum and minimum readings, is 13° C. (56° F.). A truer value determined from the 24-hourly readings for a period of 20 years, 1891 to 1910, is 12.6° C. (54.6° F.).

The departures from the mean are comparatively small in all months. The warmest month is September, with a mean of 15° C. (59.1° F.), and the coldest month, January, 9.6° C. (49.2° F.). The warmest month has practically the same departure above the mean as the coldest month has below. The annual amplitude is 5.5° C. (9.9° F.).

The monthly mean temperatures determined from hourly readings, 1891 to 1910, are:

Month.	Degrees centi- grade.	Degrees Fahren- heit.	Month.	Degrees centi- grade.	Degrees Fahren- heit.
January.....	9.6	49.2	July.....	13.6	56.4
February.....	10.7	51.3	August.....	13.9	57.0
March.....	11.1	52.1	September.....	15.0	59.1
April.....	12.1	53.8	October.....	14.7	58.5
May.....	13.1	55.7	November.....	12.9	55.2
June.....	13.5	56.3	December.....	10.1	50.2

The coldest month was January, 1890, when the mean temperature was 7.8° C. (46° F.), and the warmest month, September, 1889, when the mean was 18.3° C. (65° F.).

In an average year there are approximately 1,311 hours when the temperature is above 15.6° C. (60° F.); 4,111 hours when the tem-

perature is above 12.8° C. (55° F.); and 7,625 hours, or about 87 per cent of the entire year, when the temperature exceeds 10° C. (50° F.).

Differences between day and night temperatures are small. The warmest hour, 2 p. m., has a mean temperature of 15.1° C. (59.2° F.). The coolest hour, 6 a. m., has a mean temperature of 10.5° C. (50.9° F.).

The highest temperature ever recorded in San Francisco is 38.3° C. (101° F.). This occurred September 8, 1904, during a prolonged period of warm weather. For 4 consecutive days maximum temperatures exceeded 32.2° C. (90° F.). This was the warmest spell of which there is record in San Francisco. In the past 20 years there have been 27 days on which the temperature exceeded 32.2° C. (90° F.); but with the exception noted above there has been no period of 3 consecutive days when this temperature has been exceeded.

The lowest temperature recorded since 1871 is -1.7° C. (29° F.), which occurred January 15, 1888. In the last 20 years the temperature has not fallen below 0° C. (32° F.).

The following table gives the monthly and annual extremes of temperature, from 1871 to 1911, inclusive:

	Maximum.		Lowest maximum.		Minimum.		Highest minimum.	
	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.
January.....	26	78	14	58	-1.7	29	8	46
February.....	27	80	16	60	.6	33	8	47
March.....	27	80	17	62	.6	33	10	50
April.....	31	88	17	63	2.0	36	9	49
May.....	36	97	21	70	6.0	42	10	50
June.....	38	100	19	67	8.0	46	12	53
July.....	37	98	19	66	8.0	47	12	54
August.....	33	92	20	69	8.0	46	12	54
September.....	38	101	20	69	8.0	47	12	53
October.....	34	94	22	72	7.0	45	12	53
November.....	28	83	18	64	3.0	38	10	50
December.....	22	72	15	59	1.0	34	7	44
All years.....	38	101	14	58	-1.7	29	12	54

The absolute range of temperature from 1871 to 1911 is 40° C. or 72° F.

SUNSHINE.

The amount of sunshine received at San Francisco is not as large as might be expected, but nevertheless compares favorably with that of other cities in the United States. The average number of hours in a year, based upon hourly records from 1894 to 1910, is 2,807, or 63 per cent of the possible. The average number of hours of sunshine for different months is:

	Hours.	Per cent of possible.		Hours.	Per cent of possible.
January.....	147	50	July.....	308	68
February.....	163	63	August.....	258	61
March.....	213	67	September.....	252	68
April.....	256	66	October.....	236	68
May.....	294	67	November.....	175	58
June.....	345	75	December.....	160	54

The following table, from the Report of the Chief of the Weather Bureau, 1910-11, gives the total hours of sunshine during the year 1910 at certain of the larger cities in the United States:

	Hours.	Per cent of possi- ble.		Hours.	Per cent of possi- ble.
Baltimore.....	2,538	63	New York.....	2,750	61
Boston.....	2,547	56	Philadelphia.....	2,545	57
Chicago.....	2,778	60	Pittsburgh.....	2,164	47
Cincinnati.....	2,668	58	St. Louis.....	2,530	56
Denver.....	3,232	72	San Francisco.....	3,019	66
Kansas City.....	2,946	66	Washington.....	2,659	59
New Orleans.....	3,151	71			

It is interesting to compare the number of hours of sunshine at Mount Tamalpais for a year with the number at San Francisco, 14 miles away. In 1910 the total number of hours of sunshine at Mount Tamalpais was 3,258, or 70 per cent of the possible; at San Francisco, 3,019 hours, or 66 per cent of the possible. The difference, amounting to 239 hours, equivalent to the total sunshine of an average month, shows how much sunshine is lost at San Francisco through the summer afternoon fog. The accompanying diagrams (figs. 7 & 8) illustrate the difference in sunshine at the lower and upper stations. In some years there is a difference of as much as 500 hours in the annual amounts of sunshine at the two stations. In some seasons the lower station receives more sunshine than the upper, the clouds forming and remaining on the mountain crest. The fogs can be seen to great advantage from the station at Mount Tamalpais. Many photographic studies of characteristic fog forms have been published in the Monthly Weather Review, the Climatology of California, and elsewhere. Some of the fogs are caused by the mixing of air streams of different temperatures and different vapor content. Some are caused by cooling due to elevation and some by excessive loss of heat by radiation. It is interesting to note that in some of the summer months San Francisco receives but 68 per cent of the possible sunshine, while at Mount Tamalpais more than 90 per cent is recorded.

THE WINDS.

The prevailing drift of the surface air along the California coast is from west to east. The charts of wind direction issued each month for the North Pacific show in detail the relative strength and frequency of the surface winds on the California coast. Briefly, the summer winds may be grouped as follows: West to northwest, 75 per cent; north to northeast, 4 per cent; east to southeast, 3 per cent; south to southwest, 3 per cent; and calms, 15 per cent. The winter

winds show a greater percentage of motion from the south. South-erly gales are not infrequent, and there is a common belief that southeast is the prevalent direction in winter months. This, however, is not true. West to northwest winds have a frequency of 30 per cent; north to northeast, 18 per cent; east to southeast, 17 per cent; south to southwest, 22 per cent; and calms, 13 per cent.

It is plain from the above figures that northwest is the predominant direction along the coast in the vicinity of San Francisco. Owing to the topography there are certain deflections and changes in the direction of the wind, especially through the Golden Gate from north-west to west or even west by south.

During certain portions of the year, especially May and June, the northwest wind attains a remarkably high velocity. In May, 1902, and May, 1903, memorable northwest gales occurred. The following table gives wind data as recorded at Point Reyes Light, California:

Two memorable northwest gales at Point Reyes Light, Cal.

Date.	Average velocity, miles per hour.				Daily movement.		Maximum velocity.	Extreme velocity.	Time of maximum velocity.
	0 to 6 a. m.	6 a. m. to 12 noon.	12 noon to 6 p. m.	6 p. m. to 12 mid- night.	Total.	Average hourly.			
1902.									
May 13.....	7	4	11	10	Miles. 188	Miles. 8	Miles. 16	Miles. 16	.....
14.....	11	14	12	22	347	14	28	30	.....
15.....	29	31	31	36	756	31.5	45	50	.....
16.....	39	38	46	58	1,086	45	76	80	10.30 p. m.
17.....	64	54	67	78	1,580	66	90	96	7.00 p. m.
18.....	75	70	79	88	1,876	78	110	120	8.50 p. m.
19.....	59	45	59	64	1,360	57	75	80	7.00 p. m.
20.....	40	27	31	52	905	38	57	62	10.45 a. m.
21.....	34	12	11	22	474	20	48	50	12.50 a. m.
22.....	21	7	9	12	291	12	27	29	.....
23.....	17	7	10	15	287	12	26	30	.....
1903.									
May 13.....	13	9	11	35	410	17	48	50	10.15 p. m.
14.....	51	39	47	55	1,153	48	64	66	9.00 p. m.
15.....	43	44	68	78	1,371	57	89	93	7.55 p. m.
16.....	72	60	65	82	1,673	70	94	98	9.55 p. m.
17.....	62	42	51	67	1,339	56	89	92	12.05 a. m.
18.....	58	52	48	59	1,247	52	68	70	12.10 a. m.
19.....	45	45	47	50	1,124	47	60	62	12.15 a. m.
20.....	42	42	50	50	1,103	46	58	60	3.50 a. m.
21.....	47	47	53	57	1,227	51	64	66	8.45 a. m.
22.....	42	39	39	45	966	41	59	61	11.30 a. m.
23.....	47	19	18	30	679	28	52	54	12.45 a. m.

The following table gives comparative wind data for the gale of May, 1903; also the total movement for the month at five points in the vicinity of San Francisco. The table has especial interest because the grouping of the stations is such as to throw light on the movement of the air at the ocean level free from obstruction; at sea level near the entrance to the Gate; in the city itself on the roof of a high

building; on a headland 149 meters (490 feet), and on a mountain summit 721 meters (2,375 feet):

Stations.	Elevation.		Total for month.	Average daily.	Greatest in 24 hours.	Greatest hourly movement.
	Meters.	Feet.	Miles.	Miles.	Miles.	Miles.
Point Reyes Light.....	149	490	24,072	776	1,673	88
Mount Tamalpais.....	721	2,366	16,871	544	1,180	78
San Francisco.....	63	207	10,040	324	517	34
Point Lobos.....	76	250	15,431	488	920	60
S. E. Farallon Island.....	9	30	17,331	559	1,185	58

There is another class of high winds experienced at San Francisco, namely, the north-northeast winds of November, December, and occasionally January. These winds are different from the northwest winds of summer and are distinctly mountain winds. The highest wind velocity recorded in San Francisco, 64 miles from the northeast, occurred on November 30, 1906.

The most prevalent high wind of winter is from the southwest, closely followed by the southeast. The latter is the well-known wind preceding winter storms in this section. At San Francisco southeast winds will sometimes prevail for several days; but in most storms the wind after blowing for 12 or more hours increases in velocity to 40 miles an hour, more or less, and then shifts suddenly to the southwest, attaining a slightly higher velocity. After a few hours the velocity decreases and, with the change to northwest, the weather clears. At such times the air is remarkably pure and the distant mountains can be seen distinctly.

The average hourly wind velocity in San Francisco is nearly 10 miles and the prevailing direction west. The wind attains its greatest velocity about 4.30 p. m. and its least about 6 a. m. The average movement during the 12 hours from 7 a. m. to 6 p. m. is approximately 11 miles per hour and from 7 p. m. to 6 a. m. 9 miles per hour.

FOG.

One of the most marked climatic features of San Francisco is the prevalence of fog. In summer afternoons sea fog moves through the Gate, appearing about 1 p. m. and covering the whole sky by 3 p. m. The average depth of the fog layer is 518 meters (1,700 feet). Comparing the percentage of possible sunshine at San Francisco and Mount Tamalpais, it is at once apparent that the summer afternoon sea fog shuts out 50 per cent or more of the possible sunshine between 3 and 7 p. m. during June, July, and August. There is also curtailment of sunshine between 7 and 9 a. m. during May, June, July, August, and September.

In winter, morning fogs, or, as they are commonly called "tule" fogs, frequently occur. These are low-lying banks of condensed vapor formed by cooling due to radiation and contact. The land surfaces are much cooler than the water surfaces, and hence these fogs have a decided motion from the land to the sea. The average number of foggy days is 24 per year.

For a detailed description of fog phenomena in the vicinity of San Francisco the reader is referred to special articles in the *Monthly Weather Review*, the *Climatology of California*, and the *Meteorological Charts of the North Pacific Ocean*, 1911.

In addition to the summer afternoon sea fog, moving from west to east, and the land or tule fog of winter mornings, there is a third kind of fog which may be called smoke fog. Under certain atmospheric conditions the smoke of the city moves seaward during the forenoon and returns about 1 p. m. as a dense black pall. This is the cause of the so-called dark days. The phenomenon is of brief duration, seldom exceeding two hours; but while it lasts causes some apprehension.

HUMIDITY.

Relative humidity is a term frequently used in attempts to describe relative dampness of a locality. The term is misleading and while generally used can not give a proper basis for comparison unless temperatures are also given, inasmuch as relative humidity is only a ratio and does not indicate a fixed amount of water vapor. Thus at San Francisco relative humidity throughout the year is high; but during the summer months, owing to low temperatures, the absolute weight of water vapor per unit of volume and the vapor tension are much less than at coast stations of the Atlantic.

The following table shows mean vapor pressures and temperatures at San Francisco, New York, Chicago, and New Orleans:

San Francisco:		°F.
January..	0.282 inch.....	49.5
July.....	.384 inch.....	57.3
New York:		
January..	.125 inch.....	30.2
July.....	.588 inch.....	73.5
Chicago:		
January..	.099 inch.....	23.7
July.....	.548 inch.....	72.3
New Orleans:		
January..	.316 inch.....	53.0
July.....	.810 inch.....	81.3

This table explains why, notwithstanding high relative humidity in summer, the vapor tension and absolute humidity are low at San Francisco.

The highest relative humidity occurs in July, from 1 a. m. until 7 a. m., and equals or exceeds 95 per cent. The lowest relative humidity occurs in October, about 1 p. m., and is about 52 per cent. The vapor pressure is greatest in July, about 1 p. m., amounting to 0.410 inch. The vapor pressure is lowest in December, about 4 a. m., when it is less than 0.250 inch.

RAINFALL.

Rainfall records have been maintained in San Francisco for a period of 63 years. The greatest 24-hour rainfall occurred on January 28, 1881, when 4.67 inches fell. The next greatest 24-hour rainfall was on September 24, 1904, when 3.58 inches fell. A detailed statement of excessive rains will be found elsewhere. The longest rainless period was in 1903, when no rain fell from April 16 until October 9, 175 days. In 1911 there was no rain from June 6 to October 1, 116 days.

Some of the months of heaviest rain were: January, 1862, when 24.36 inches of rain fell, and 18 days of the month were rainy. In January, 1911, 13.79 inches fell, distributed over 18 days. In January, 1909, 10.51 inches fell, but there were 26 rainy days, making it in this sense the rainiest month known at San Francisco. In January, 1890, 9.61 inches fell, and there were 23 rainy days. In January, 1907, there were 21 rainy days, but the total rainfall amounted to only 4.41 inches, which is less than a normal rainfall, notwithstanding that the number of rainy days was nearly double the normal.

The rainiest February was in 1878, when 12.52 inches fell on 19 days. In February, 1887, 9.24 inches fell and there were 16 rainy days. In February, 1891, 7.26 inches fell and there were 19 rainy days; in February, 1902, 7.27 inches fell and there were 19 rainy days; in February, 1909, 7.53 inches fell and there were 18 rainy days.

The rainiest March was in 1879, when 8.75 inches fell and there were 14 rainy days; in 1907 the rainfall amounted to 8.42 inches and there were 20 rainy days; in 1904, the rainfall amounted to 6.01 inches and there were 23 rainy days; in 1884, 8.24 inches fell and there were 16 rainy days.

The rainiest April was in 1880, when 10.06 inches fell and there were 17 rainy days. The average number of rainy days in April is 6, and the average rainfall 1.64 inches.

From May until October, inclusive, there is little rain.

The rainiest November was in 1885, when 11.78 inches fell and there were 19 rainy days. The average number of rainy days in November is 7.

The rainiest December was in 1866, when 15.16 inches fell and there were 18 rainy days; in December, 1889, 13.81 inches fell and

there were 24 rainy days; in December, 1880, 12.33 inches fell and there were 19 rainy days.

Number of rainy days in the year.—In the past 62 years, 1850 to 1911, there have been 4,207 rainy days. The yearly distribution is: January, 11; February, 10; March, 11; April, 6; May, 4; June, 1; July, 0; August, 0; September, 2; October, 4; November, 7; December, 11. For the year, average number 67.

MONTHLY RAINFALL.

JANUARY.

From records covering a period of 63 years, 1850 to 1912, the mean January rainfall is 4.90 inches. The greatest rainfall was in 1862, when 24.36 inches fell and the least was in 1852, when 0.58 of an inch fell. There were 5 years in which the rainfall exceeded 10 inches and 3 years in which the rainfall did not exceed 1 inch. The largest number of rainy days, 23, occurred in 1890 and the smallest number in 1852, when there were 4 rainy days. The average number of rainy days is 11. There have been 16 Januarys when the number of rainy days equaled or exceeded 15. In January, 1859, there were 26 consecutive days of fair weather.

FEBRUARY.

The mean rainfall is 3.55 inches. Reduced to a 30-day normal, best obtained by eliminating the rainfall of leap years and adding twice the rainfall on the 14th, we have 3.81 inches. The average number of rainy days is 10. The heaviest February rainfall was 12.52 inches in 1878 and the least, no rain, in 1864. Rainfalls exceeding 10 inches occurred once, in 1878, and rainfalls of less than 1 inch occurred 13 times. The largest number of rainy days in any February was 19, which occurred in 1878, 1891, and 1902. There have been 11 Februarys when the number of rainy days did not exceed 5. The largest number of consecutive rainy days was 15, which occurred in 1891. The largest number of consecutive fair days was in February, 1864, when there were 29.

MARCH.

The mean rainfall is 3.36 inches. The greatest amount was in 1879, when 8.75 inches fell. The next rainiest March was in 1907, when 8.42 inches fell. The least was in 1898, when only 0.24 of an inch fell. There have been 12 years in which the rainfall for March equaled or exceeded 5 inches, and 8 in which the total monthly amount did not exceed 1 inch. In 1908 there were 18 consecutive days without rain, and in 1911, 21 days, with exception of a trace on one day. In 1900 there were 23 consecutive days during which

only a trace of rain fell. In 1875 there were 17 consecutive fair days, and in 1877, 21 consecutive fair days. In 1861 the month was without rain until the 23d. The average number of rainy days is 10. The largest number of rainy days in any month was in 1904 when there were 23, of which 19 were consecutive. The smallest number of rainy days was in 1901 when there were only 3. The heaviest 24-hour rainfall occurred on March 5, 1879, when 3.31 inches fell.

APRIL.

The mean rainfall is 1.64 inches. The month of heaviest rainfall was in 1880, when 10.06 inches were measured. There have been 6 Aprils out of the past 63 in which the rainfall equaled or exceeded 5 inches. There have been 27 in which the amount of rain did not exceed 1 inch. No rain fell in April, 1857, and there was only a trace of rain during April, 1909. The largest number of consecutive rainy days occurred in 1880, when it rained for 11 days. The average number of rainy days in April is 6. The greatest 24-hour rainfall was 2.43 inches on April 24, 1896.

MAY.

The mean rainfall for May is 0.73 of an inch. The rainiest May was in 1883, when 3.52 inches fell. There have been 5 Mays during the past 63 years when practically no rain fell. During 18 years the rainfall for May exceeded 1 inch. The average number of rainy days is 4. The greatest number of consecutive rainy days was 5, which occurred in 1860, 1889, and 1906. The largest number of rainy days in April was 11, in 1860 and 1883. The greatest 24-hour rainfall, 1.29 inches, occurred on May 5, 1889.

JUNE.

The mean rainfall for June for a period of 62 years is 0.16 of an inch. The month is practically rainless, only 3 times has the rainfall exceeded 1 inch. The heaviest June rainfall occurred in 1884, when 2.57 inches fell. The average number of rainy days is 2. In 1888 there were 9 rainy days. The heaviest 24-hour rainfall occurred on June 12, 1884, when 1.23 inches fell. Of the past 62 years 20 have been without rain during the month of June and 27 have had a rainfall not exceeding 0.01 of an inch.

JULY.

The mean rainfall for July is 0.02 of an inch. In the past 62 years there have been only 3 showers in which the total amount exceeded 0.05 of an inch. Most of the rainfalls did not exceed 0.01 of an inch. The greatest 24-hour rainfall was 0.23 of an inch on July 16, 1886.

AUGUST.

August, like July, is practically a rainless month. The mean rainfall is 0.02 of an inch. There has never been an August when the total rainfall exceeded 0.25 of an inch. Only 14 of the 62 months under consideration have had a rainfall exceeding 0.01 of an inch. The greatest 24-hour rainfall was 0.12 on August 26, 1858.

SEPTEMBER.

The mean rainfall is 0.30 of an inch. This, however, is larger than might be expected and is caused by phenomenal rainfall in September, 1904. In the 5 days, 22d to 26th, more than 5 inches of rain fell. The average number of rainy days is 2. The greatest number of consecutive rainy days is 5. There have been 19 Septembers without rain. Only once has the rainfall exceeded 5 inches and only 4 times has it exceeded 1 inch. The greatest 24-hour rainfall, 3.09 inches, occurred on September 23, 1904.

OCTOBER.

The mean rainfall is 1.02 inches. The heaviest rainfall was in 1889, when 7.28 inches fell. Other rainy Octobers were, 1899, 3.92 inches; 1876, 3.36 inches; and 1849, 3.14 inches. There have been 9 Octobers without rain. The average number of rainy days is 4, and the greatest number, 13, occurred in 1889. The heaviest 24-hour rainfall, 2.06 inches, occurred on October 21, 1858.

NOVEMBER.

The mean rainfall is 2.55 inches. The heaviest rainfall was in 1885, when 11.78 inches fell. Other rainy Novembers were, 1849, when 8.66 inches fell; 1859, when 7.28 inches fell. November, 1890, was without rain. The rainfall for November was less than 1 inch in 21 years. The average number of rainy days is 7. The greatest number of rainy days was 19 in 1885. The greatest 24-hour rainfall, 3.98 inches, fell on November 26, 1864, and again on November 23, 1874.

DECEMBER.

The mean rainfall is 4.56 inches. The heaviest rainfall was in 1866, when 15.16 inches fell. Other rainy Decembers were, 1852, 13.20 inches; 1871, 14.36 inches; 1880, 12.33 inches; 1889, 13.81 inches, and 1894, 9.01 inches. December, 1876, was rainless. Less than an inch of rain fell in 1854, 1865, 1874, 1878, 1883, and 1901. The average number of rainy days is 11. The greatest number, 24, was in 1889. The greatest 24-hour rainfall, 4.28 inches, fell on the 19th, 1866.

In connection with the absence of rain during December, 1876, it may be noted that there was no rain between November 16, 1876, and January 16, 1877. Or, in other words, there was a period of 60 consecutive days without rain in midwinter.

THUNDERSTORMS.

Few thunderstorms occur at San Francisco. In the past 20 years there have been 28, but not a single one that could be considered as severe. The following table shows the distribution: January, 2; February, 3; March, 1; April, 3; May, 1; June, 1; July, 1; August, 2; September, 2; October, 3; November, 3; and December, 6. The greatest number recorded in any one year was 8, in 1906. During the past 20 years there have been 8 years without record of a thunderstorm. The storms are mild in character, the lightning flashes of moderate intensity, and the thunder usually limited to a few peals. Damage from lightning is practically unknown, although some flagpoles have been shattered and one or two trees struck in the past 60 years.

HAIL.

There have been 56 hailstorms in the past 20 years. January and December are the months of maximum frequency. There is no record of any hailstorm occurring during June, July, August, and September.

SNOWSTORMS.

Snow is of rare occurrence. During winter storms the tops of the hills in the southwestern portion of the city are occasionally whitened by snowflakes. These melt rapidly and snow of appreciable depth is rare. However, snow can be seen frequently during winter months on Mount Tamalpais, Mount Diablo, and the peaks of the Mount Hamilton Range. The heaviest snowfall in the Bay Section occurred January 9, 1913, when Mount Tamalpais and Angel Island were covered.

DATES OF SNOWFALL AT SAN FRANCISCO SINCE MARCH 1, 1871.

January 21, 1876.—Light snow fell for ten minutes.

December 31, 1882.—Heavy snow fell from 11.30 a. m. to 4.20 p. m., amount 3.5 inches.

February 6, 1883.—A few flakes of snow fell during the day.

February 7, 1884.—Snow fell at intervals during the day, depth varying from 1 to 2 inches.

February 5, 1887.—Snow fell during the day; depth at office 3.7 inches, while in the western portion of the city it was fully 7 inches deep.

January 4, 1888.—A few flakes of snow fell during the day.

January 16, 1888.—Light snow fell to the depth of 0.1 inch.

March 2, 1894.—A few flakes of snow fell during the day.

March 2, 1896.—Snow mixed with rain fell at intervals during the day.

March 3, 1896.—Heavy snow fell during the night; depth at office at 8 a. m. 0.5 inch.

February 3, 1903.—Snow, large flakes, 11.16 to 11.20 a. m.

March 5-6, 1908.—Trace of snow fell.

February 26 and 27, 1911.—0.04 of an inch of snow fell.

January 9, 1913.—Light snow fell, which melted quickly.

TABLE 1.—Annual sea-level pressure at San Francisco.

Year.	Inches.	Year.	Inches.	Year.	Inches.
1873.....	30.027	1886.....	30.026	1899.....	30.053
1874.....	30.018	1887.....	30.023	1900.....	30.043
1875.....	30.024	1888.....	29.998	1901.....	30.050
1876.....	30.004	1889.....	29.998	1902.....	29.939
1877.....	29.992	1890.....	30.035	1903.....	30.058
1878.....	29.968	1891.....	30.036	1904.....	30.060
1879.....	30.017	1892.....	30.032	1905.....	30.025
1880.....	30.031	1893.....	30.055	1906.....	30.024
1881.....	30.028	1894.....	30.058	1907.....	30.038
1882.....	30.045	1895.....	30.043	1908.....	30.019
1883.....	30.039	1896.....	30.041	1909.....	30.054
1884.....	29.985	1897.....	30.055	1910.....	30.033
1885.....	30.012	1898.....	30.047	1911.....	30.033

Mean of 38 years, 30.027 inches.

TABLE 2.

This table gives the highest temperature for each month, from 1871 to 1912, as given by self-registering mercurial thermometer.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Absolute annual maximum.
1871.....			74	69	76	77	66	69	78	84	78	62	84
1872.....	61	64	64	71	81	92	70	77	82	80	67	62	92
1873.....	66	64	73	75	75	67	74	72	69	79	72	59	79
1874.....	61	62	62	72	83	82	73	71	89	78	69	62	89
1875.....	62	63	67	81	71	79	71	70	82	79	68	65	82
1876.....	58	67	70	75	81	93	78	78	86	72	70	64	93
1877.....	69	67	73	64	75	92	76	75	92	81	69	64	92
1878.....	62	65	66	70	78	73	73	73	78	78	68	68	78
1879.....	62	70	77	76	75	85	76	89	86	81	65	64	89
1880.....	60	62	66	69	84	82	73	73	79	78	75	61	84
1881.....	63	69	76	76	75	71	83	70	80	72	66	63	83
1882.....	60	61	73	74	74	68	73	69	83	76	64	65	83
1883.....	60	70	74	63	86	95	80	82	91	74	67	62	95
1884.....	58	71	68	68	50	71	83	75	73	76	70	64	83
1885.....	62	69	76	75	77	67	78	81	87	76	70	67	87
1886.....	68	71	73	79	86	83	78	85	94	79	75	66	94
1887.....	73	67	78	78	97	90	70	74	89	87	74	69	97
1888.....	63	76	74	88	81	80	93	85	88	87	74	65	93
1889.....	64	75	79	77	88	75	83	80	89	87	77	63	89
1890.....	59	64	70	81	85	81	80	85	81	86	78	60	86
1891.....	72	63	76	81	75	100	81	92	86	85	78	64	100
1892.....	66	66	80	68	90	73	90	92	88	79	78	64	92
1893.....	60	69	78	72	74	90	74	72	72	74	74	72	90
1894.....	58	62	66	82	72	69	76	91	94	89	79	61	94
1895.....	63	69	70	73	89	86	83	80	89	83	83	60	89
1896.....	63	72	72	66	91	79	72	72	81	85	66	64	91
1897.....	60	66	63	84	88	83	82	70	92	85	68	63	92
1898.....	59	70	74	87	63	89	88	72	80	81	78	66	89
1899.....	78	80	74	80	80	75	73	78	73	94	65	63	94
1900.....	64	68	71	69	71	74	73	82	92	83	79	63	92
1901.....	62	75	78	72	81	82	75	72	78	91	75	72	91
1902.....	58	65	68	78	70	73	77	82	83	77	67	62	83
1903.....	59	66	64	71	77	96	91	77	92	85	67	66	96
1904.....	65	60	66	84	86	90	73	75	101	79	74	61	101
1905.....	63	71	79	71	85	67	98	73	87	84	74	67	98
1906.....	68	71	74	76	72	82	82	76	82	86	77	61	86
1907.....	61	68	60	81	80	85	78	74	78	90	78	68	90
1908.....	64	65	76	85	79	86	77	80	89	82	74	61	89
1909.....	60	62	67	80	80	94	77	82	93	86	74	63	94
1910.....	59	64	77	87	90	74	76	79	82	89	76	68	90
1911.....	72	67	79	73	85	77	84	79	82	87	77	71	87
1912.....	65	68	67	66	87	93	71	77	94	81	.....	.....	.....

TABLE 3.

This table gives the lowest temperature for each month from 1871 to 1912, as given by self-registering alcohol thermometer.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Absolute annual minimum.
1871.....			45	45	46	48	50	51	53	51	45	42	42
1872.....	43	47	48	43	48	52	52	53	52	48	44	41	41
1873.....	46	40	45	43	48	50	52	54	53	49	47	44	40
1874.....	39	43	42	47	50	48	49	51	50	50	44	40	39
1875.....	39	43	42	40	49	49	52	50	52	51	49	39	39
1876.....	36	41	41	44	45	49	51	51	52	52	50	42	36
1877.....	42	46	47	46	48	51	53	52	51	49	49	42	42
1878.....	39	45	46	44	48	51	51	52	52	51	47	40	39
1879.....	40	44	47	46	45	49	51	50	52	49	45	34	34
1880.....	37	38	39	42	45	49	52	51	50	50	41	42	37
1881.....	44	45	40	48	49	50	49	52	50	45	44	43	40
1882.....	40	38	41	44	45	49	52	50	50	48	45	34	34
1883.....	36	35	44	43	48	51	50	52	53	48	44	40	35
1884.....	43	35	45	45	49	52	52	52	52	50	50	40	35
1885.....	43	46	50	47	50	50	54	52	52	53	50	44	43
1886.....	41	41	41	44	48	48	50	48	50	46	45	43	41
1887.....	42	33	45	44	46	48	49	49	50	49	42	40	33
1888.....	29	42	38	46	47	53	51	51	50	50	47	43	29
1889.....	40	39	47	49	48	52	50	49	51	51	47	40	39
1890.....	36	36	41	46	47	49	49	50	52	48	46	39	36
1891.....	39	40	43	40	48	48	50	50	51	48	47	37	37
1892.....	40	42	42	44	47	47	50	50	51	47	42	38	38
1893.....	36	39	40	40	46	47	47	50	50	47	44	37	36
1894.....	36	38	37	42	44	47	48	49	49	49	46	40	36
1895.....	38	41	40	44	48	48	50	50	51	48	42	39	38
1896.....	40	44	33	41	45	47	50	52	52	47	38	42	33
1897.....	40	38	39	45	47	48	47	49	50	48	44	39	38
1898.....	36	43	40	44	46	49	47	47	50	50	43	38	36
1899.....	40	34	42	43	43	47	48	50	48	46	48	37	34
1900.....	42	44	43	45	47	47	48	50	47	48	45	40	40
1901.....	37	38	44	41	46	47	47	49	50	50	49	41	37
1902.....	38	40	41	44	47	48	47	52	51	49	45	39	38
1903.....	37	37	41	42	46	48	48	46	50	51	46	42	37
1904.....	40	40	40	44	45	48	50	49	49	52	49	38	38
1905.....	40	42	42	49	48	49	49	50	51	49	44	39	39
1906.....	41	46	41	43	42	48	49	50	48	47	40	40	40
1907.....	36	43	38	45	47	48	50	51	53	51	45	41	36
1908.....	40	40	40	45	46	46	48	50	50	47	44	35	35
1909.....	38	42	41	44	44	47	49	49	50	48	43	38	38
1910.....	36	38	44	46	48	48	48	48	48	47	44	43	36
1911.....	41	38	42	42	46	47	49	49	49	50	42	39	38
1912.....	40	44	43	44	46	48	49	50	52	48			

TABLE 4.—Mean hourly temperatures in degrees Fahrenheit, 1891-1910.

Hours.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1 a. m.....	48	50	50	51	52	53	53	54	56	56	53	49	50.2
2 a. m.....	47	49	50	50	52	52	53	54	56	55	53	48	51.7
3 a. m.....	47	49	49	50	51	52	53	54	56	55	52	48	51.4
4 a. m.....	47	48	49	50	51	52	53	54	56	55	52	48	51.2
5 a. m.....	47	48	49	50	51	52	53	54	56	55	52	48	51.3
6 a. m.....	46	48	49	50	51	52	53	54	55	55	52	47	50.9
7 a. m.....	46	48	49	50	52	54	54	54	56	55	52	47	51.4
8 a. m.....	46	48	50	52	54	56	55	56	57	56	52	47	52.4
9 a. m.....	47	49	51	54	56	58	57	57	59	57	53	48	53.8
10 a. m.....	48	50	52	56	57	60	59	59	61	59	54	49	55.4
11 a. m.....	49	52	54	57	59	61	60	60	63	61	56	50	56.8
12 noon.....	50	53	55	58	59	61	61	61	64	63	58	52	58.0
1 p. m.....	51	55	56	59	60	62	61	62	65	64	59	53	58.8
2 p. m.....	52	56	57	59	60	62	62	62	65	64	60	54	59.3
3 p. m.....	53	56	57	59	60	61	61	62	64	64	60	54	59.1
4 p. m.....	53	56	56	58	59	60	60	61	63	63	59	54	58.4
5 p. m.....	52	55	55	57	58	60	59	60	62	61	58	53	57.5
6 p. m.....	52	54	54	56	57	58	58	58	60	60	57	52	56.4
7 p. m.....	51	53	53	54	55	57	56	57	59	59	57	52	55.3
8 p. m.....	50	52	53	54	54	55	56	56	58	58	56	51	54.5
9 p. m.....	50	52	52	53	54	55	55	56	58	58	55	50	53.9
10 p. m.....	49	51	51	52	53	54	54	55	57	57	55	50	53.3
11 p. m.....	49	50	51	52	53	53	54	55	57	57	54	50	52.8
Midnight.....	48	50	50	51	52	53	54	54	56	56	54	49	52.4
Mean.....	49.2	51.3	52.1	53.8	55.7	56.3	56.0	57.0	59.1	58.5	55.2	50.2	54.6

NOTE ON EXPOSURE OF ANEMOMETERS AT SAN FRANCISCO.

The elevations of the anemometer above ground (street) have been as follows: January 1, 1891, to November 1, 1892, 109 feet; November 1, 1892, to April 18, 1906, 167 feet; May 1, 1906, to September 30, 1906, 42 feet; October 1, 1906, to September 31, 1910, 204 feet.

These elevations, however, can not be used without explanation concerning elevation of cups above the roof or nearest deck surface. Unfortunately most of the roofs occupied have had on them platforms or raised surfaces, and, as in the case of the Mills Building, the platform serving as a deck for Weather Bureau instruments was itself on top of an extra story 14 feet in height. This superstructure was 10 feet from the west wall of the building and about 30 feet from the south wall.

In the Mills Building and the Merchants Exchange are large interior courts, or light wells, which may have affected the results.

The approximate heights of the cups above the roof proper are: Merchants Exchange, October 1, 1906, to December 31, 1910, 18 feet; Mills Building, November 1, 1892, to April 18, 1906, 30 feet; Phelan Building, January 1, 1891, to November 1, 1892, 12 feet; No. 3014 Clay Street, May 1, 1906, to September 30, 1906, 4 feet.

TABLE 5.—Average hourly wind velocity in miles.

[Period, 1891-1910.]

Hours.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1 a. m.	6.4	6.3	7.2	7.4	8.6	9.5	10.0	9.5	7.6	6.5	5.6	5.9	7.5
2 a. m.	6.4	6.1	6.9	7.1	8.0	9.0	9.5	9.0	7.1	5.6	5.6	6.0	7.2
3 a. m.	6.4	5.8	6.8	6.7	7.4	8.3	8.8	8.2	6.7	5.4	5.6	6.0	6.8
4 a. m.	6.4	5.9	6.6	6.3	7.1	7.7	8.4	8.0	6.2	5.3	5.5	6.1	6.6
5 a. m.	6.5	5.9	6.6	6.3	7.0	7.4	8.0	7.7	6.0	5.1	5.5	6.2	6.5
6 a. m.	6.5	5.8	6.5	6.1	6.8	7.1	7.8	7.3	5.8	5.0	5.5	6.4	6.4
7 a. m.	6.7	5.9	6.4	7.3	6.8	7.0	7.8	7.2	5.8	5.0	5.5	6.5	6.5
8 a. m.	6.9	6.2	6.8	6.9	7.3	7.6	8.1	7.5	6.0	5.3	5.7	6.6	6.7
9 a. m.	7.2	6.7	7.3	7.6	7.8	8.1	8.4	7.8	6.5	5.6	5.9	6.9	7.2
10 a. m.	7.6	7.2	7.9	8.2	8.7	9.3	9.3	8.8	7.1	6.1	6.3	7.2	7.8
11 a. m.	7.8	7.4	8.4	9.2	10.4	11.4	11.2	10.5	8.3	6.5	6.5	7.3	8.8
12 noon	7.9	7.6	9.2	10.3	12.7	14.4	14.2	12.9	10.5	7.6	6.8	7.4	10.1
1 p. m.	8.2	8.3	10.6	13.2	15.0	16.9	16.9	15.7	12.9	9.5	7.3	7.7	11.8
2 p. m.	8.6	9.3	12.0	14.8	16.4	18.9	19.1	18.0	15.3	11.2	8.2	7.7	13.3
3 p. m.	8.5	10.1	13.2	15.7	17.5	20.0	20.6	19.6	16.7	12.6	8.9	7.7	14.3
4 p. m.	8.4	10.4	13.9	16.5	18.1	20.6	21.5	20.3	17.6	13.2	9.3	7.6	14.8
5 p. m.	8.1	10.4	13.6	16.6	18.1	20.8	21.8	20.5	17.8	13.7	9.6	7.2	14.8
6 p. m.	7.8	9.9	13.0	16.0	17.7	20.2	21.1	19.8	17.2	13.0	9.1	7.1	14.3
7 p. m.	7.6	9.3	11.9	14.6	16.1	18.7	19.5	18.2	15.2	11.2	8.2	6.5	13.1
8 p. m.	7.2	8.7	10.7	12.8	14.4	16.8	17.4	16.3	13.2	9.6	7.6	6.3	11.8
9 p. m.	7.0	7.8	9.4	11.0	12.7	14.7	15.3	14.3	11.5	8.5	6.9	6.2	10.4
10 p. m.	6.6	7.4	8.4	10.1	11.2	12.7	13.7	12.5	10.3	7.6	6.4	6.2	9.4
11 p. m.	6.3	6.9	7.9	9.1	10.1	11.4	12.2	11.3	9.1	6.8	6.1	6.1	8.6
12 midnight	6.3	6.4	7.4	8.1	9.2	10.2	11.0	10.2	8.2	6.3	5.8	6.0	7.9
Average...	7.2	7.6	9.1	10.3	11.5	12.9	13.4	12.5	10.3	8.0	6.8	6.7	9.7

TABLE 8.—San Francisco rainfall, monthly, seasonal, and annual, 1849-1912.

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Seasonal.	Year.	Annual.
1840-50.													33.10	1860	17.40
1850-51.	0	0	0	3.14	8.66	6.20	8.34	1.77	4.53	0.46	0	0	7.42	1861	15.60
1851-52.	0	0.02	1.03	0.21	0.92	7.10	0.72	0.54	1.94	1.23	0.32	0.02	18.46	1862	27.29
1852-53.	0	0	0	0.80	5.31	13.20	3.92	1.42	4.96	6.37	0.38	0	23.87	1863	21.17
1853-54.	0	0.04	0.46	0.12	2.26	2.32	3.88	8.04	3.51	3.12	0.02	0.06	35.26	1864	22.45
1854-55.	0	0.01	0.15	2.43	0.34	0.87	3.67	4.77	4.64	5.00	1.88	0	23.76	1865	26.39
1855-56.	0	0	0	0	0.67	6.76	9.40	0.50	1.60	2.94	0	0	21.66	1866	22.31
1856-57.	0.02	0	0.07	0.45	2.79	3.75	2.46	8.59	1.62	0.76	0.03	0.12	19.91	1867	20.96
1857-58.	0	0.05	0	0.93	3.01	4.14	4.36	1.83	5.55	1.55	0.34	0.06	19.91	1868	23.46
1858-59.	0.05	0	0	2.74	0.69	6.14	1.28	6.32	3.02	3.27	1.55	0	22.27	1869	21.39
1859-60.	0	0.02	0.03	0.06	7.28	1.57	1.64	1.60	3.99	2.14	2.86	0.06	22.27	1870	21.18
1860-61.	0.21	0	0	0.91	0.58	0.64	24.36	3.72	4.08	0.51	1.00	0.06	19.72	1871	25.52
1861-62.	0	0	0.02	0	4.10	9.64	1.83	7.53	2.20	0.73	0.74	0.06	49.27	1872	38.63
1862-63.	0	0	0	0.52	2.15	2.35	3.63	3.19	2.06	1.61	0.78	0	13.74	1873	15.10
1863-64.	0	0	0.03	0	2.55	1.80	1.83	0	1.52	1.57	0.63	0	10.08	1874	16.04
1864-65.	0.21	0.21	0.01	0.13	6.68	8.91	5.14	1.34	0.74	0.94	1.46	0.04	24.73	1875	14.06
1865-66.	0	0	0.24	0.26	4.19	0.58	10.88	2.12	3.04	0.12	1.46	0	22.93	1876	36.28
1866-67.	0	0	0.11	0	3.35	15.16	5.16	7.20	1.58	2.36	0	0	34.92	1877	30.17
1867-68.	0	0	0.04	0.20	3.41	10.69	9.50	6.13	6.30	2.31	0.08	0.02	38.84	1878	22.59
1868-69.	0	0	0	0.15	1.18	4.34	6.35	3.90	3.14	2.19	0.20	0	19.31	1879	16.24
1869-70.	0	0	0.12	1.29	1.19	4.31	3.89	4.78	2.00	1.53	0.23	0.01	14.11	1871	27.53
1870-71.	0	0.02	0.03	0	0.43	3.38	3.07	3.76	1.05	0.89	0.18	0	14.11	1872	22.45
1871-72.	0	0	0	0.07	2.81	14.36	4.00	6.90	1.59	0.81	0.18	0	30.78	1873	27.45
1872-73.	0.01	0	0.04	0.11	2.79	6.95	5.66	3.94	3.78	0.43	0	0.02	16.66	1874	18.55
1873-74.	0	0.08	0	0.83	9.72	9.72	1.58	2.21	3.36	0.90	0.66	0.14	24.73	1875	22.62
1874-75.	0	0	0.02	2.69	6.55	0.33	8.01	0.32	1.30	0.10	0.24	1.02	20.56	1876	22.63
1875-76.	0	0	0	0.24	7.27	4.15	7.55	4.92	5.49	1.29	0.31	0.01	31.19	1877	23.54
1876-77.	0.01	0.01	0.38	3.36	0.25	4.15	11.97	12.52	1.08	0.06	0.18	0.01	11.04	1878	33.26
1877-78.	0.02	0.02	0	0.65	1.57	2.66	3.52	1.87	4.56	1.06	0.16	0.01	35.18	1879	33.26
1878-79.	0.01	0.01	0.55	1.27	0.03	0.58	2.23	1.87	8.75	1.89	2.35	0.06	24.44	1879	30.07
1879-80.	0.01	0.02	T.	0.78	4.07	4.40	3.23	4.90	2.08	10.06	1.12	0	26.66	1880	30.07
1880-81.	0	0	0	0.05	0.33	12.33	8.69	4.66	0.90	2.00	0.22	0.69	29.86	1881	23.73
1881-82.	0	0	0.25	0.54	1.94	3.85	1.68	2.96	3.45	1.22	0.21	0.04	16.14	1882	18.67
1882-83.	0	0	0.42	2.66	4.18	2.01	1.92	1.04	3.01	1.51	3.52	0.01	30.12	1883	15.43
1883-84.	0	0	0.26	1.48	1.60	0.92	3.94	6.65	8.24	6.33	0.23	2.57	32.38	1884	38.82
1884-85.	0.04	T.	0.33	2.55	0.26	7.68	2.53	0.30	1.01	3.17	0.14	0.19	18.10	1885	24.90
1885-86.	T.	T.	0.11	0.72	11.78	4.99	7.42	0.24	2.07	5.28	0.37	0.01	33.05	1886	20.02
1886-87.	0.06	0.06	0.01	1.48	0.84	2.07	1.90	9.24	0.84	2.30	0.06	0.07	19.04	1887	19.04
1887-88.	0.23	T.	T.	T.	0.99	3.34	6.81	0.94	3.60	0.11	0.38	0.27	16.74	1888	23.03
1888-89.	0.01	0.01	0.98	0.13	3.99	5.80	1.28	0.72	4.73	1.18	2.17	0.03	23.86	1889	36.94
1889-90.	T.	T.	T.	7.28	2.90	13.81	9.61	5.16	1.96	1.65	1.07	0.10	45.85	1890	25.43
1890-91.	0	0	0.31	0	0.56	5.62	0.98	7.26	1.96	1.39	1.96	0.11	17.58	1891	21.11
1891-92.	0.02	0.02	0.77	0.04	0	3.25	2.42	2.90	2.85	1.39	1.83	T.	18.53	1892	22.08
1892-93.	0	0	0.02	1.65	3.91	5.08	3.05	2.75	4.08	1.03	1.03	0.03	18.47	1893	17.91
1893-94.	0.02	0	0.21	0.16	4.18	2.25	5.98	2.69	-0.60	0.50	1.31	0.56	21.87	1894	24.32

TABLE 8.—*San Francisco rainfall, monthly, seasonal, and annual, 1849-1912—Continued.*

Season.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Seasonal.	Year.	Annual.
1849-50	T.	0	1.05	1.73	0.88	9.01	6.99	2.31	1.90	1.24	0.60	0	24.70	1895	17.13
1850-51	0.01	0	0.77	0.14	1.78	1.43	8.14	0.24	2.85	5.16	0.72	0	21.25	1896	28.25
1851-52	0.04	0.09	0.52	1.55	1.58	1.34	9.34	4.34	4.54	0.77	0.41	0.22	23.43	1897	16.40
1852-53	T.	T.	0.16	1.26	1.05	1.22	1.12	2.11	0.24	0.19	1.44	0.19	9.21	1898	8.31
1853-54	0	T.	1.06	0.98	0.46	1.62	3.67	0.10	7.41	0.62	0.56	0.01	8.28	1899	23.23
1854-55	T.	T.	0.46	3.22	3.79	2.65	4.11	0.44	1.91	0.08	0.32	0.06	16.67	1900	18.72
1855-56	T.	T.	0.46	1.43	3.01	1.37	5.79	5.04	0.80	1.64	0.69	T.	21.17	1901	18.72
1856-57	T.	T.	0.78	0.64	3.48	1.80	1.73	7.74	2.65	0.98	1.06	0	18.58	1902	18.13
1857-58	T.	T.	T.	1.77	1.25	2.32	3.73	1.74	6.23	0.56	T.	T.	18.58	1903	18.52
1858-59	T.	T.	5.07	2.37	1.92	1.83	1.06	5.89	6.15	1.33	0.30	T.	20.49	1904	24.74
1859-60	0.02	0.06	T.	T.	0.92	2.89	1.04	2.79	3.15	0.29	0.26	0	23.49	1905	16.44
1860-61	0.08	0.11	0.18	0.03	1.59	2.08	3.40	4.29	8.02	0.12	2.75	0.56	26.44	1906	26.44
1861-62	T.	0.02	0.11	1.36	0.94	6.80	4.41	3.89	8.42	0.11	1.23	1.23	26.17	1907	27.47
1862-63	0.02	0.01	0.13	0.61	1.34	3.06	4.88	8.39	0.90	0.22	0.94	0.01	17.35	1908	16.40
1863-64	T.	T.	0.80	1.23	2.43	5.59	10.51	7.33	3.77	T.	T.	T.	26.67	1909	31.28
1864-65	0	0	0.65	0.66	0.45	1.73	13.79	3.02	3.78	0.31	0.03	0.02	19.53	1910	12.58
1865-66	T.	0	T.	0.28	0.60	2.54	2.47	0.41	4.67	0.89	0.28	0.03	25.49	1911	26.00
1866-67	T.	0	1.25	0.49	1.94	1.30	.....	.....	4.10	1.38	1.47	0.81	14.06	1912	15.62
Averages.....	0.02	0.02	0.32	1.00	2.55	4.51	4.90	3.55	3.36	1.64	0.73	0.16	22.58	.....	22.90

TABLE 9.—*Greatest precipitation (inches and hundredths) in twenty-four hours for each month.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Greatest annual.
1871.....			0.57	1.28	0.13	0.01	0.00	0.02	0.00	0.07	1.24	3.14	3.14
1872.....	2.36	1.28	0.73	0.35	0.15	0.03	0.01	0.00	0.04	0.11	2.06	2.33	2.36
1873.....	1.02	0.82	0.54	0.36	0.00	0.01	0.01	0.05	0.00	0.77	0.80	2.33	2.33
1874.....	1.61	0.81	0.65	0.70	0.23	0.13	0.00	0.00	0.02	1.58	3.98	0.15	3.98
1875.....	2.19	0.27	0.45	0.06	0.14	0.90	0.00	0.00	0.00	0.22	2.37	1.50	2.37
1876.....	1.76	1.80	1.59	0.80	0.24	0.04	0.01	0.01	0.20	1.39	0.19	0.00	1.80
1877.....	1.63	0.52	0.56	0.08	0.18	0.01	0.02	0.00	0.00	0.36	0.56	1.11	1.63
1878.....	1.98	1.92	1.01	0.61	0.14	0.01	0.01	T.	0.45	1.27	0.45	0.33	1.98
1879.....	1.04	1.66	3.31	0.72	0.93	0.05	0.01	0.02	T.	0.56	1.38	1.55	3.31
1880.....	1.03	0.64	0.57	2.21	0.84	0.00	0.00	0.00	0.00	0.05	0.32	2.36	2.36
1881.....	4.67	1.37	0.69	1.09	0.17	0.41	0.00	0.00	0.25	0.21	1.34	1.35	4.67
1882.....	0.57	0.82	0.86	0.44	0.15	0.02	0.00	0.00	0.26	1.40	2.41	0.70	4.67
1883.....	1.30	0.71	1.63	0.76	1.23	0.01	0.00	0.00	0.42	1.19	1.01	0.28	1.63
1884.....	1.44	1.62	2.21	1.66	0.12	1.23	0.00	0.03	0.21	1.15	0.19	2.07	1.63
1885.....	0.97	0.15	0.55	2.03	0.04	0.10	0.05	T.	0.11	0.70	2.58	2.78	2.78
1886.....	2.40	0.18	0.65	1.36	0.21	0.01	0.23	0.00	0.01	0.72	0.77	1.10	2.40
1887.....	0.80	3.60	0.62	1.45	0.03	0.07	T.	0.01	0.18	0.00	0.48	1.14	3.60
1888.....	1.58	0.38	1.34	0.11	0.19	0.10	0.01	0.01	0.92	0.05	1.68	1.51	1.68
1889.....	0.81	0.59	3.08	0.30	1.29	0.03	0.01	T.	T.	2.03	0.92	1.46	3.08
1890.....	2.08	1.63	1.86	0.55	0.53	0.05	0.02	0.00	0.31	0.00	0.00	1.90	2.08
1891.....	0.75	3.38	0.68	1.20	0.61	0.10	0.09	0.02	0.63	0.03	0.26	2.21	3.38
1892.....	1.06	1.03	0.90	0.38	1.15	T.	0.00	0.00	0.02	0.91	1.46	2.34	2.34
1893.....	1.39	1.06	0.98	0.71	0.14	0.03	0.02	0.00	0.12	1.10	1.69	0.97	1.69
1894.....	2.61	1.05	0.34	0.30	0.68	0.22	T.	0.00	1.04	0.64	0.88	1.64	2.61
1895.....	1.96	1.44	0.67	0.89	0.27	0.00	0.01	0.00	0.62	0.06	1.06	0.51	1.96
1896.....	1.85	0.18	0.64	2.43	0.34	0.00	0.04	0.06	0.41	1.46	2.79	1.65	2.79
1897.....	1.06	1.23	1.42	0.20	0.61	0.19	T.	T.	0.08	1.41	0.42	1.02	1.42
1898.....	0.33	0.78	0.13	0.19	1.23	0.18	0.00	T.	0.73	0.45	0.36	0.70	1.23
1899.....	0.98	0.08	2.15	0.45	0.77	0.01	0.00	T.	0.00	1.94	1.51	1.17	2.15
1900.....	1.92	0.50	0.90	0.36	0.22	0.04	T.	T.	0.45	0.34	1.66	0.74	1.92
1901.....	1.75	1.95	0.67	0.88	0.46	T.	T.	T.	0.67	0.43	1.20	0.01	1.95
1902.....	0.35	1.08	0.69	0.23	0.56	0.00	T.	T.	T.	0.69	0.77	0.85	1.08
1903.....	1.00	0.63	1.30	0.39	T.	T.	0.00	T.	T.	0.15	2.39	1.06	2.39
1904.....	0.59	2.73	1.32	0.40	0.30	T.	0.02	0.05	3.58	0.72	0.66	0.57	3.58
1905.....	1.08	1.23	0.93	0.49	1.18	0.00	0.00	T.	T.	T.	0.38	0.65	1.23
1906.....	1.06	1.32	1.37	0.51	1.42	0.23	0.05	0.08	0.12	0.01	0.67	2.57	2.47
1907.....	0.91	1.52	1.82	0.08	0.02	0.74	T.	0.02	0.11	0.99	0.02	0.96	1.52
1908.....	2.10	2.04	1.41	0.10	0.24	0.01	0.02	0.01	0.10	0.44	0.70	0.99	2.10
1909.....	1.61	1.87	1.16	T.	T.	T.	T.	0.00	0.67	0.82	0.97	1.41	1.87
1910.....	0.83	0.64	1.17	0.23	0.02	0.02	T.	0.00	0.04	0.48	0.27	0.99	1.17
1911.....	2.48	0.68	1.98	0.81	0.15	0.03	T.	0.00	T.	0.16	0.45	0.66	2.48
1912.....	1.06	0.19	2.09	0.80	0.74	0.68	T.	0.00	1.21	.....	.....	.....	.....
Year.....	4.67	3.60	3.31	2.43	1.42	1.23	0.23	0.08	3.58	2.03	3.98	3.14	4.67

Dates when the precipitation equaled or exceeded 2.50 inches in any consecutive 24 hours: 1871, December 17–18, 2.83 inches; 1871, December 18–19, 3.14 inches; 1874, November 22–23, 3.98 inches; 1879, March 4–5, 3.31 inches; 1881, January 28–29, 4.67 inches; 1885, November 23–24, 2.58 inches; 1885, December 21, 2.78 inches; 1887, February 4–5, 3.60 inches; 1889, March 12–13, 3.08 inches; 1891, February 14–15, 3.38 inches; 1894, January 19–20, 2.61 inches; 1896, November 23–24, 2.79 inches; 1904, February 11–12, 2.73 inches; 1904, September 23, 3.58 inches.

Maximum rates of rainfall: 1901, February 22, 5 minutes, 0.17 of an inch; 10 minutes, 0.21; 1902, October 23, 5 minutes, 0.16 of an inch; 10 minutes, 0.20; 1903, February 7, 5 minutes, 0.19 of an inch; 10 minutes, 0.23; 1904, September 23, 5 minutes, 0.16 of an inch; 10 minutes, 0.32; 1904, September 23, in 15 minutes, 0.43; in 30 minutes, 0.74; in 1 hour, 0.97; in 2 hours, 1.29; in 16 hours 15 minutes, 3.58 inches; 1912, March 5, 5 minutes, 0.10; 10 minutes, 0.28; 15 minutes, 0.53; 20 minutes, 0.72; 25 minutes, 0.77; and 30 minutes, 0.78 of an inch.



FIG. 1.—Hourly pressure, San Francisco. (Sea level).



FIG. 2.—Monthly sea level pressure, San Francisco.

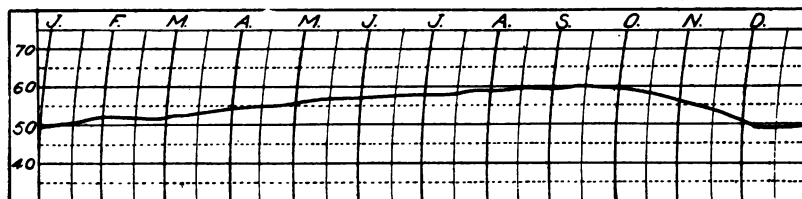


FIG. 3.—Mean monthly temperature at San Francisco, 1891-1910.

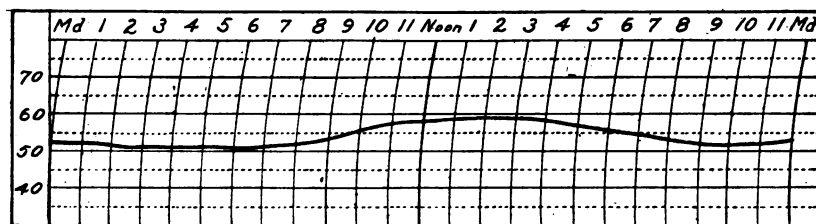


FIG. 4.—Average hourly temperature at San Francisco, 1891-1910.

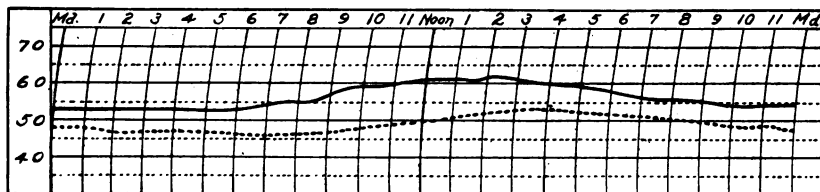


FIG. 5.—Mean hourly temperature—Summer ———, winter

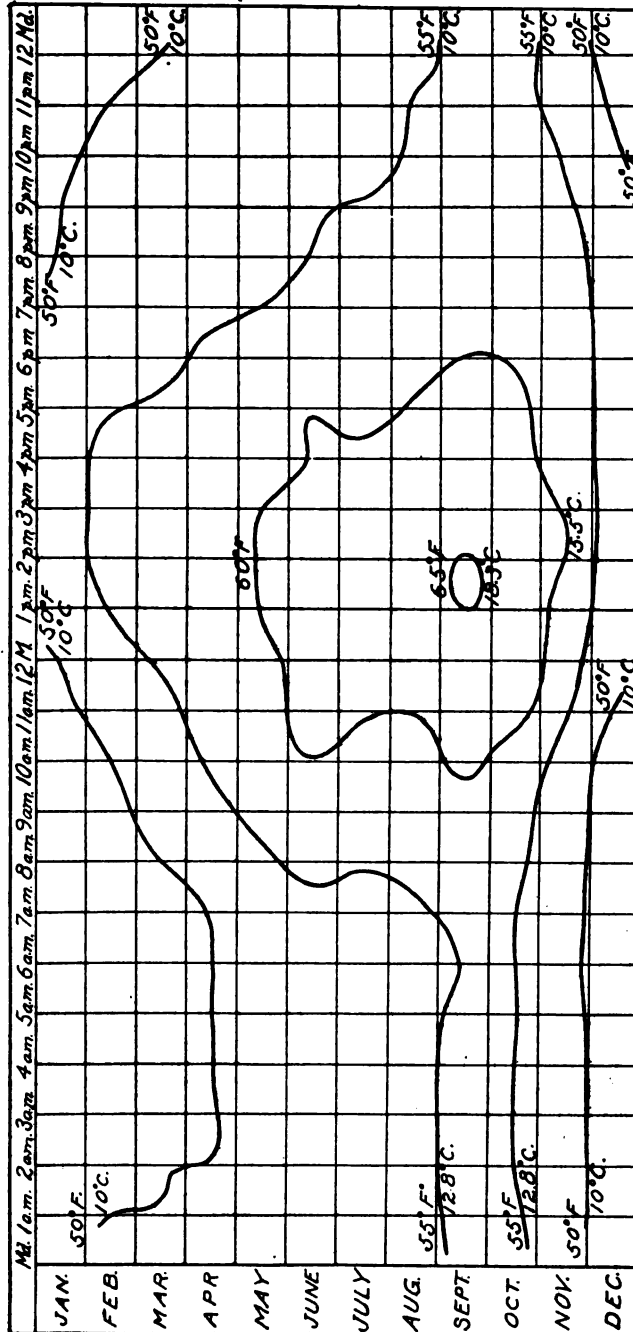


FIG. 6—Isopleth of temperature at San Francisco, 1891-1910.

1000 ft.
of
Clouds

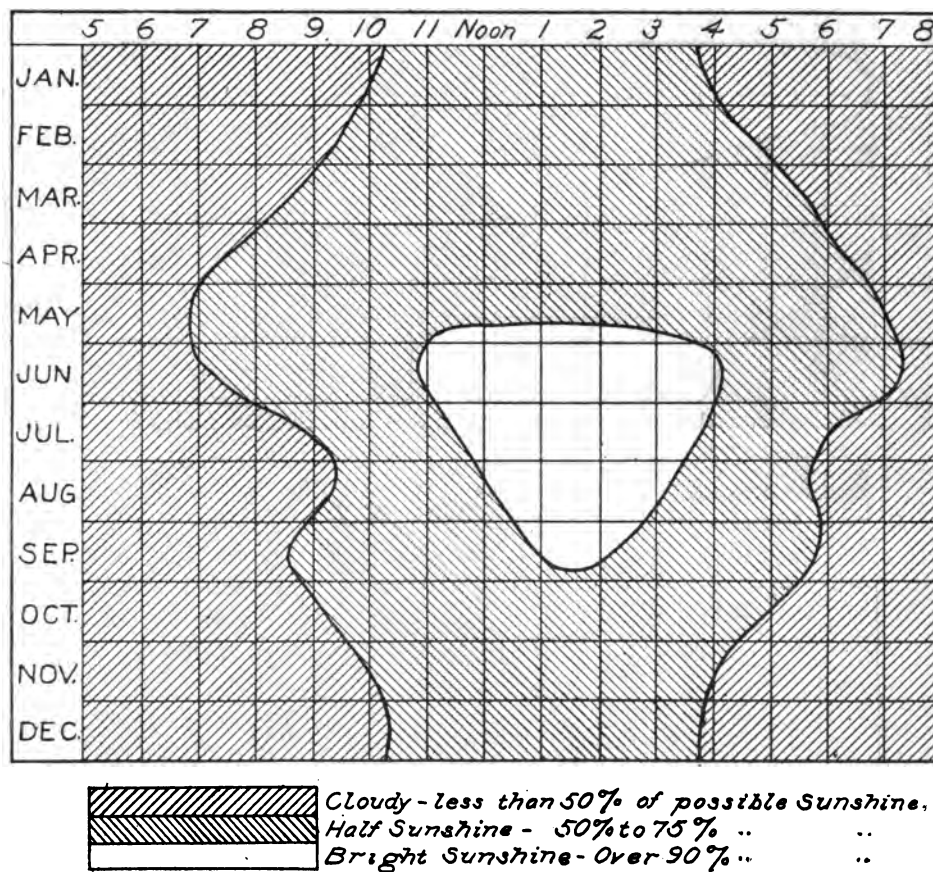


FIG. 7.—Sunshine at San Francisco, 1893-1911.

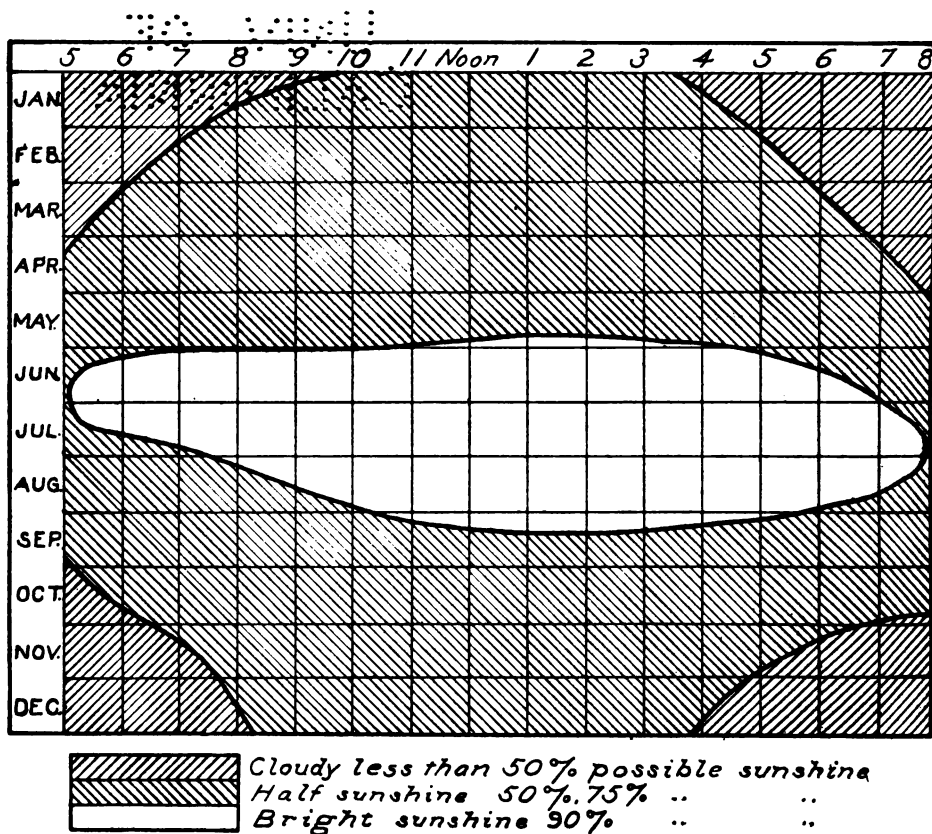


FIG. 8.—Sunshine at Mount Tamalpais, 1890-1911.

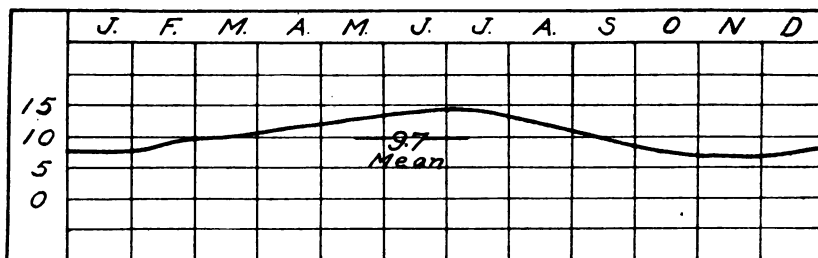


FIG. 9.—Average monthly wind velocity, 1891-1910.

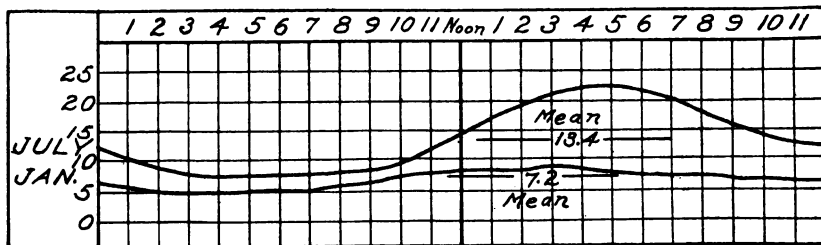


FIG. 10.—Hourly wind velocity, 1891-1910.

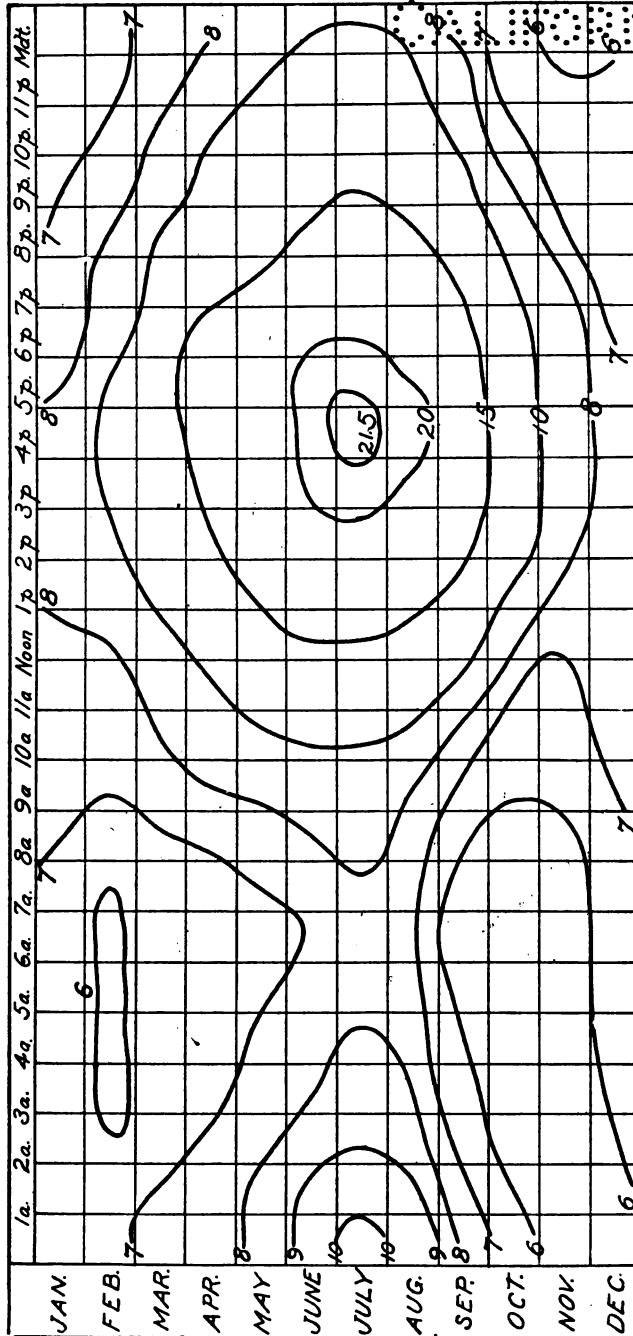


FIG. 11.—Isopleth of wind, San Francisco, 1891-1910.

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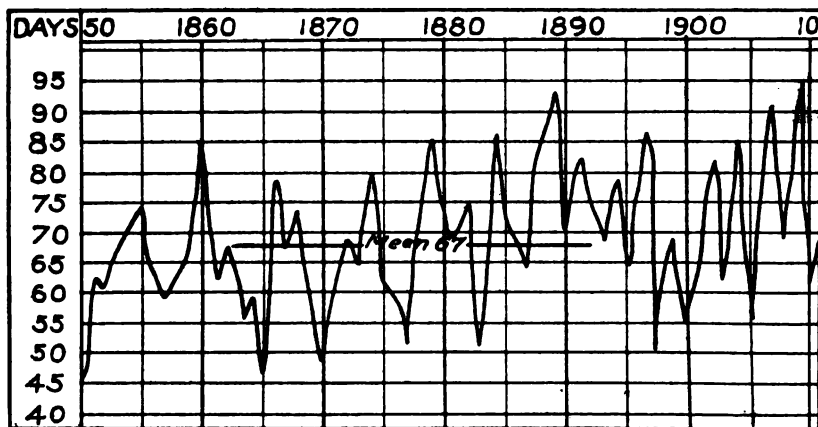


FIG. 12.—Annual frequency of rainy days, San Francisco.

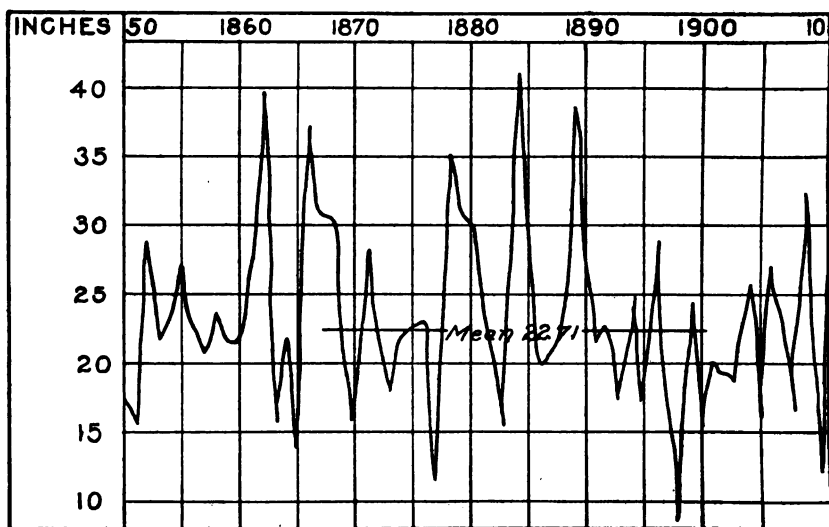


FIG. 13.—Annual rainfall at San Francisco, 1850-1911.

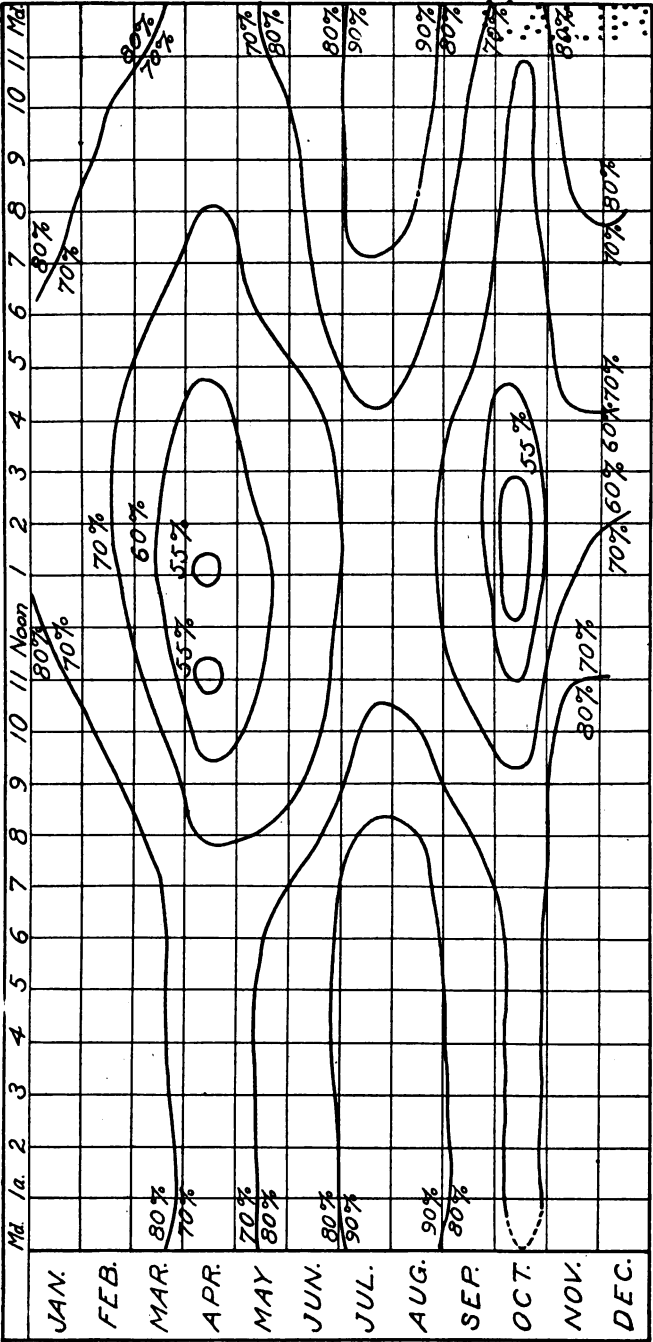


FIG. 14.—Isopleth of relative humidity, 1908-1909, San Francisco.

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